ELECTRIC TRACTION.

Six Lectures delivered in March 1902 at the Civil Engineering College, Sibpur,

BY

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UNIFORM WITH THE ABOVE

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AUTHOR'S NOTE.

In order to treat the subject satisfactorily the six lectures have been printed as five only.

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LECTURES ON ELECTRIC TRACTION

LECTURE I.

SYSTEMS OTHER THAN OVERHEAD.

Introduction.—I am much gratified at the honour paid me in being asked a second time to deliver a course of lectures at this College, and I take this opportunity of saying that I trust my previous course has proved of practical benefit to some of you. I am very pleased to be able to congratulate the students who have taken up the special electrical classes on the success of those who have preceded them in obtaining appointments. This has been invariably the case, I believe, and the demand has actually been in excess of the supply up to the present time. And yet it may safely be said that the electrical era in India has scarcely commenced; for so far as I know there are, excluding private plants, only three public electric-supply stations and one tramway system actually working, and about half-a-dozen more schemes in contemplation or under construction. This province is well to the fore in the matter, and Calcutta as is only right holds the first place with its extensive installations both for general electrical supply and for tramways, the latter nearly completed. But what a field is yet untouched! Light railways, which in most countries are almost exclusively electrical, are here worked by steam where they exist at all; transmission of power is represented by one large industrial scheme in the Mysore gold-fields, and another under construction in the north; and other cities, besides Calcutta and Dacca, must surely require electric light and fans and punkha-pulling machines. That the new Imperial Electricity Bill, introduced the other day in the Supreme Legislative Council, will assist the development of electrical enterprise may be considered certain.

But I must get to my subject, for in half-a-dozen lectures it is obviously no easy matter to deal with a question on which scores of large books have been written, and yet to give an intelligible idea of the main features of electric

traction. Just as in my previous course of lectures I selected what seemed likely to be the work you would see most of, so now it is useless for me to attempt to cover the whole field; but after a general survey I shall confine myself mainly to one system. And there is another difficulty in which I find myself involved, namely that when I keep to general matters I am telling the special electrical students nothing they do not already know, while when I come to the particular I run the risk of being unintelligible to a majority of those present.

Classification.—Electric traction may be employed in a number of capacities, which may be conveniently classified under four headings—

(*i*) Self-contained vehicles other than tramcars.
(*ii*) Urban tramways.
(*iii*) Light railways and inter-urban tramways.
(*iv*) Railways

Under (*i*) come electrical motor cars and launches, with neither of which we need concern ourselves greatly except to say that, though quite practicable, they have not so far proved commercially successful against the rivalry of kerosine and the lighter oils. The great weight of lead accumulators, their heavy cost of upkeep when subject to rough usage, and the meagre facilities for charging them, put them out of competition with a source of energy which, even when not available at the nearest shop, can always be stored in advance.

To urban and inter-urban tramways I shall chiefly confine myself, though my 4th heading (Railways) is one on which the future will have the chief say. Until comparatively recently the question of using electrical energy as the motive power on ordinary rail-roads had been scarcely touched, but it has been boldly attacked by Mr. Langdon in a masterly paper read before the Institution of Electrical Engineers, followed by a most interesting discussion. The main contention was that economy in working expenses would be enhanced by generating in bulk at great central stations and transmitting at extra high pressure to sub-stations along the line. Obviously in this country, where distances are enormously greater and traffic is far less, such a plan would be futile as regards the trunk roads. Even in England the general trend of the discussion led me to the conclusion that the steam-engine has a long tether yet as regards trunk lines, but there seems every probability of its supersession on the short and crowded lines in and

about large towns, while for underground railways it is already virtually obsolete. But it is doubtful whether the merits and possibilities of electric traction for hill railways have been recognised fully as yet; one such scheme has indeed been talked about and reported on in Cashmere, but it has not yet gone beyond the stage of paper discussion. Mountain railways electrically worked already exist in many countries, and where rack systems are used there is hardly a limit to the grade that can be negotiated. Even by ordinary rail adhesion grades steeper than any on the Darjeeling Railway are easily managed, and in the Isle of Man there is an electric tramway rising by this means to a height of about 2,000 feet by gradients as steep as 1 in 12 and even 1 in 10, though for descending and for emergencies a special grip rail is provided between the tracks. The success of such an electric railway would depend on the facilities for obtaining power cheaply, and this, again, involves either cheap coal or convenient water-power. In this connection one point is very apt to be overlooked by the general public, who have an idea that power obtained from water costs nothing. Of course that is a grave fallacy, for, in the first place, the use of water-power only gets rid of one item—fuel—in the generating expenses, while it generally adds very greatly to two other items in the yearly-recurring works cost—interest on capital, and, in India at any rate, heavy maintenance charges. Remember that the capital cost of hydraulic works on an extensive scale, especially if the water has to be brought from a considerable distance, or if extensive tunnels, dams, reservoirs or long pipe lines are required, is apt to be much in excess of the cost of engines and boilers and their accessories, even though turbines are comparatively simple and inexpensive. And such works are also much more liable to damage from floods, excessive rainfall, and landslips, which no precautions do more than mitigate. No doubt the advantage, on the whole, is on the side of water-power, but this is not a universal rule.

Systems.—Let us next make out a list of the different methods by which electric tramways and railways can be worked. Roughly, there are five main divisions in each of which various systems have been evolved :—

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(*a*) self-contained cars,
(*b*) conduit systems,
(*c*) surface-contact systems,
(*d*) third-rail systems,
(*e*) trolley systems ;

and while concerning myself mainly with the last in subsequent lectures, I will to-day speak about the others. Each has its advantages and disadvantages, and no one system is at all likely to prove so immeasurably superior as to oust the rest entirely.

It is not necessary for me to use up the limited time at my disposal in discussing the relative advantages of electric and other forms of traction, or the cost of constructing and working them. Many books and papers deal with these considerations and the upshot of it all is that as a rule electric traction, except with accumulator cars, is the best paying as an investment, which is the consideration that ultimately determines most matters of the kind. In working expenses, cable tramways are cheaper than electrical ones, but the cost of construction is higher and the system has no flexibility. Of horse tramways we have seen enough in Calcutta to show that they are unsuited for such a climate as that of the plains of India, while steam and gas trams have been almost forgotten during the period in which there has been such an enormous extension of electric traction. It is invariably found that when a horse tramway converts to electric traction, the expenses diminish and the number of passengers and the receipts increase. We will proceed, then, to consider briefly the first of the systems enumerated above, which is on a totally different footing to the remaining systems and needs separate treatment.

Self-contained cars.—When a revolution occurs in the structure and design of secondary batteries, so that they become really suitable for use on cars—whether running on rails or not—there will certainly be an immense field open to this class of electric traction; in fact, one may go further and say that for urban traffic no other system would have a chance. Every car carrying its own supply of energy, the stopping of one through any mishap would not affect the rest in the least, except that the one next behind it would have to push it into the nearest siding. There would be no complicated system of feeders and distribution; no rail bonding; and the telegraph and municipal bodies and owners of magnetic apparatus would no longer go in fear of their wires, pipes, and instruments being affected by short circuits, induction or electrolysis. But that era does not show any distinct signs of coming yet.

The energy efficiency of a good battery is almost 80 per cent. under favourable conditions, though it would perhaps seldom exceed 70 per cent. under tramcar conditions, and the works

cost of a supply-station, whose chief work was the charging of batteries, would be very low, since the plant could be kept always working at about full load. It is obvious, therefore, that traction cells are not yet what is required, or they would be used far more than is the case. The two chief disadvantages of the lead accumulator plate are its great weight and its mechanical weakness; the weight alone would not be so serious a matter, though each car usually has to carry about 3,000 lbs.—40 maunds—of battery, but the high rate of deterioration and consequent high cost of renewal and upkeep has more than counterbalanced all the other advantages which the self contained car has by rendering them incapable of commercial competition. In the city of Birmingham accumulator tramcars had a long trial under distinctly favourable conditions in one section of the place. The steepest grade on the section was 1 in 28, and the greater part was fairly level, but the cost per car-mile came out far in excess of other lines owing to the continual renewal of the cells. Several types were tried successively, and in some cases the makers boldly undertook the maintenance of their cells at a fixed percentage on their prime cost; but the result was never such as to justify the further introduction of the system.

You must remember that the case is not parallel with that of primary batteries. In the latter the active element—zinc as a rule—combines entirely with and dissolves in the electrolyte, and then needs complete renewal. So many pounds of zinc will give us so much energy just as if it were coal, and the reason primary batteries are not more used is that zinc is too expensive a fuel so long as coal holds out. The zinc is bought in a purified state and is amalgamated so as to diminish local action, but it does not have to undergo expensive or complicated processes of preparation, and the cost of battery zinc is not greatly in excess of the cost of ordinary spelter. Far different is the case with accumulators, for the cost of "formed" battery plates bears little comparison to the cost of the same sized plate of plain lead; and though the lead in a secondary battery combines with the electrolyte, the products are insoluble, and the alternate charge and discharge still leave the contents of the cell practically as they were after the previous charge or discharge. There is comparatively little wastage due to chemical action, but the plates become useless, partly through the loss of material which drops to the bottom, partly owing to the bad contact which results between the active material and the backing of the plates from the buckling and rough usage to which the cells

are subjected, and partly from the active material becoming clogged by inactive bye-products. If in setting up a battery of accumulators one could put in so many tons of lead at the current price of that metal *plus* the cost of sawing it up into plates and burning on the connections, and if after a year or two one could renew the whole of the plates and sell the old lead—peroxide, sulphate, etc.—back to the manufacturers at scrap lead price, the arrangement would be a satisfactory one and would be extensively used, but unfortunately you cannot do this economically.

In self-contained cars the batteries are placed either under the seats or right under the body of the car, and they are in any case arranged with a view to easily removing one set and replacing it by another, all the connections being made automatically. For control the usual arrangement is to divide the battery into a number of parts, (say four) each complete in itself, the terminals of each being brought up to the controlling switches. By means of these the battery can be connected with all four parts in parallel, or two series two parallel, or all four series, and sometimes a $\frac{3}{4}$-speed contact is included as well, arranged by putting three groups in series and the fourth in parallel with one of them or inactive. These different arrangements are shown in the following diagram—figure 1.

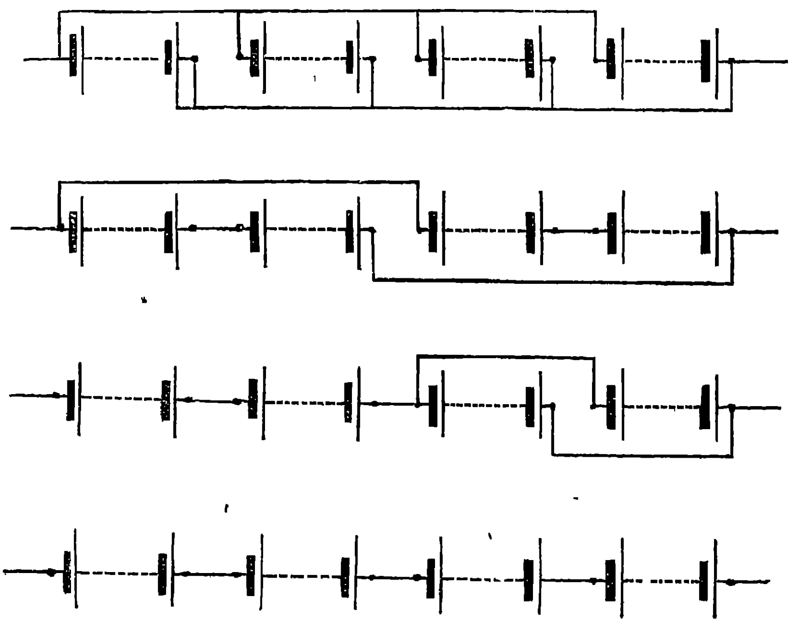


Figure 1.—Regulation of accumulator cars

Combination of Accumulator and other systems.—On the Continent there are several successful instances of the combined use of the overhead or conduit and self-contained system, which I saw at Hanover and Dresden; the trolley or plough being used except just in those parts of the town where, either because of the number of aërial lines already existing or for æsthetic reasons, it appeared desirable to the Town Council to veto the trolley line or slot. There is no question at all that to the visitor to those places the effect is excellent; but unless their batteries are better than any available to us, there must be some of the usual troubles encountered. Of course, the batteries are comparatively small and light ones, and of comparatively simple construction, since they are never discharging for more than a few minutes at a time, and can be constantly charged while the car is running, and the fact that they do not need to be taken in and out of the car for charging is also in their favour. Two miles is about the longest run made on the batteries, and the speed is kept down somewhat on these sections. In order to charge direct off the trolley wire a large number of cells are necessary—somewhere about 208 on each car. Speed regulation is carried on by the use of rheostats, which, though wasteful, are alone practicable on these combination cars unless two separate controllers are used.

GENERAL NOTES ON ELECTRIC TRACTION FROM POWER-STATIONS.

All the remaining systems which I enumerated just now, and which I am going to deal with in turn have this one thing in common to them, that the power for working them is generated in one or more power-stations which transmit the energy to the cars as they travel. In the majority of cases the energy is generated of the nature and at the pressure used on the motors, allowing for loss in the conductors; but sometimes it is generated at high pressure and transmitted to sub-stations, where it is converted to lower pressure for use on the motors. Either continuous or alternating or polyphase currents may be used both in the generating stations and at the motors, but in the great majority of cases it is the first, and I shall say very little about the others. When the power is transmitted from a distance at high pressure, polyphase currents are generally used, but even in such cases it is usual to instal rotary convertors in the sub-stations and to use continuous current at low pressure on the motors.

Definitions.—In order to clear the ground a little, let me explain to you one or two definitions of terms constantly

used. I take these definitions from the electrical rules of the Government of India, which were revised last year, and which are dated 12th July 1901. They are printed *in extenso* in Appendix I, and are not likely to be greatly altered under the new Electricity Act.

Rule 1 (7).—The expression *feeder* means a portion of any main used to convey energy (*i.e.*, electrical energy) from the source of supply to the point or points where it is distributed for use.

Rule 1 (14).—The expression *pressure* means the difference of electric potential between any two conductors through which a supply of energy is given, or between any part of either conductor and the earth.

Rule 1 (15), (16), (17).—The expressions *pressure, high pressure*, and *extra high pressure* are used in relation to electric-supply lines, conductors, circuits, and apparatus according to the conditions of the supply delivered through the same or particular portions thereof: where the conditions of the supply are such that the pressure may at any time exceed 500 volts, if continuous, or 250 volts, if alternating, but cannot exceed 3,000 volts, whether continuous or alternating, the supply shall be deemed to be a "high-pressure supply;" where the conditions of the supply are such that the pressure may, on either system, exceed 3,000 volts, the supply shall be deemed to be an "extra high-pressure supply."

Rule 54—(*Traction rules for continuous current*).—One of the two conductors used for transmitting energy from the generator to the motor, and hereinafter referred to as the *line*, shall be in every case insulated from earth. The other, hereinafter referred to as the *return*, may be insulated throughout or may be insulated in such parts and to such extent as is provided in the following rules—

*　　*　　*　　*　　*

Now this term *earth* continually crops up, and gives rise to a great deal of misunderstanding, owing to confusion between *earth* returns and *earthed* returns. For telegraphic and telephonic work the earth itself is often used to complete the circuit in place of a return wire, that is to say, there is a real earth return. But in the worst constructed electric tramway of early days, the rails were at least intended to act as the return, while in the best constructed modern systems, in which an uninsulated return is used, there is very little current carried by the general mass of the earth. The rails are largely used, and they are rendered

electrically continuous for this purpose, and in some cases a subsidiary insulated return feeder is also laid to give an alternative low resistance path back to the generators. The current will naturally take the best conducting path, so, though the rails and the return are at the same potential as the earth, the latter is not appreciably used as a return: it is an *earthed*, and not an *earth*, return. Now, just as a telephone system may have either complete metallic circuits or a metallic lead and an earth return, so can an electric traction system have either an insulated metallic circuit or a metallic insulated line and an earthed return. Both methods have been adopted in one place or another, and each has advantages of its own: the former in that troubles from interference with other people's property or circuits are avoided, the latter for its simplicity and lower cost of construction.

Now, referring to the definitions I gave you just now, let us see how the terms come in. In my previous lectures I explained the use, in a lighting system, of feeders—the mains, that is, whose function is to feed the distribution network. In electric traction the case is similar, but there will be many more feeding points as a rule in a given number of miles of streets; for it is convenient, and by rule 61 necessary, to divide up the line wire into half-mile sections, between every two of which an emergency switch must be inserted. The advantage of this arrangement is that a fault on the line need only affect one such section, which can be completely disconnected at both ends and from the feeder, and repaired while the cars are running on the other sections.

The pressure used on the great majority of electric traction lines on British soil is 500 volts, *i.e.*, the maximum allowable "low pressure." The shock due to that pressure is not generally speaking dangerous, though it is just on the verge of what may be considered so. In some cases, chiefly at present in the experimental stage, a line pressure of 2,000 volts and upwards has been used with the overhead system, but with none of the other systems would this be feasible. With regard to the use of the rails as a return, I shall defer my remarks until dealing with the overhead system, but the methods and precautions adopted there to ensure good conductivity are also applicable to all systems using the rails in this manner.

Conduit systems of electric traction.—In conduit systems proper, not including the more recently developed "surface-contact" systems, which I am treating later on, the "line"

conductor is carried in a channel underground, either between the rails or as part of one rail, the current being taken into the car through a plough running in a slot at the top. In most systems both line and return are side by side in the conduit, as there are practical difficulties in the way of using the rails for the return, but in any case the slot, which is to all intents just the same as the slot on a cable tramway, is the only feature showing externally. Provided the slot is narrow enough not to be a source of danger to the ordinary traffic, which in some early examples it was, the system is an excellent one in crowded towns having a dry climate, though the heavy initial cost of construction militates against its use for inter-urban work, in which it cannot compete with the overhead system. There are difficulties in the way of effecting repairs to the line and the conduit which have never been altogether overcome, and also in maintaining good insulation. But for India the system has been tried and found wanting, as indeed might have been predicted at the present time, even had not Madras made the experiment. An open conduit on the street level carrying a bare conductor at a considerable difference of potential from earth resented the presence of water, especially in such quantities that drainage could not carry it off as quickly as it ran in, and constant trouble resulted. It is quite true, as you probably have been told, that pure water is not a conductor to any appreciable extent, and this is not merely a scientific truth but a practical fact; for in potentiometer work, when using water-cooled manganin standard resistances, it has been found quite practicable to connect the resistance tube to the water-supply even when working the resistance in connection with an earthed electric-supply system, provided the connection is made by an India-rubber hose; the insulation resistance in one case (Fisher's "Potentiometer"), being one megohm for 30 feet of ¾ inch hose filled with ordinary water from the main.

However, the water that is found in an Indian street is very far from pure, and during heavy rains it will speedily fill up any conduit and get to the conductors. For this reason it is not advisable that I should take up much time in going into the details of conduit systems; but I will give a brief description of a few so far as the underground part is concerned. The consideration of the car and its electrical arrangements for driving and control can stand over until we come to the overhead system, as there is not any great difference here.

The Love conduit at Washington, U. S. A., is 20 inches deep and 14 inches wide (maximum), getting narrower towards the top. The slot is $\frac{5}{8}$ inch wide, and the plough running in this collects the current from the two conductors. The slot is left between two inverted channel iron pieces, and the conductors are placed one underneath each channel, where they are protected as far as possible both from access of water, from earthing and short circuiting by falling pieces of metal, and from deliberate injury. They are about 5 inches apart, and are placed close to the top, so that nearly the whole conduit is available to carry off ordinary rainfall to the sumps; they are of $\frac{1}{2}$ inch hard drawn copper bar, of figure of eight-cross section on the straight (see figure 2) and circular at curves, and arrangements are made for taking up expansion on every section of 500 feet—

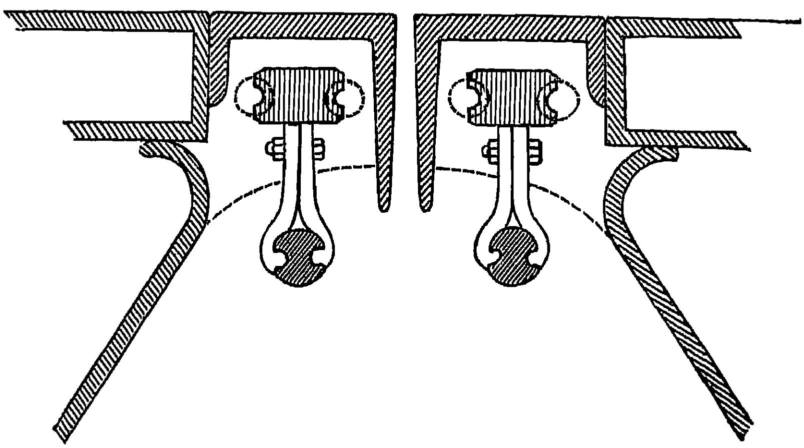


Figure 2.—Love Conduit.

Each conductor is suspended on gun-metal ears, which are fixed to insulating blocks hung from the yoke which maintains the slot rails in position. They are fixed at intervals of about 9 feet on straight runs, but closer on curves, where the construction is more rigid. A small amount of latitude for expansion and contraction is allowed for by arranging that the insulating blocks can slide either way on their supporting bolts, stops being fixed to prevent "creeping," *i.e.*, the movement due to the reaction to the motion of the collector. The contact is a rolling wheel pressed on by a spring, as in the case of overhead construction, two of these wheels being placed side by side, pressed outwards from one another by another spring, and carried on

a pendant bar, which is free to swing sideways sufficiently to run freely: in fact, very similar to the grip bar of a cable car (see figure 3).

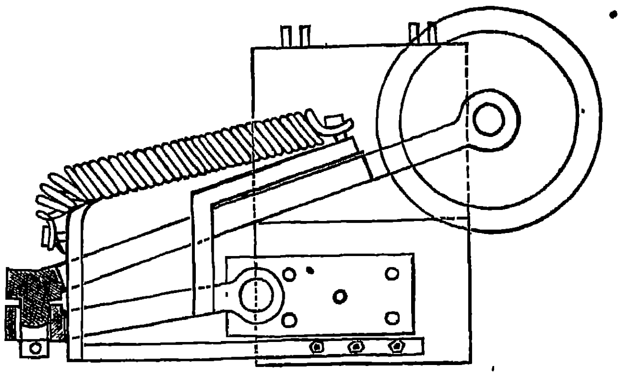


Figure 3.—Collector for Conduit.

If it is necessary to open up the conduit, it can be done by removing the slot rails, for which arrangements are made, but the operation takes some time. But despite certain disadvantages, I prefer this system to any other conduit system I have actually examined.

Other systems, those of the General Electric Company of America and of Siemens and Halske, etc., are used in New York, Berlin, and elsewhere. They differ considerably in detail from the above, though the principle is the same.

The conduit in one form, laid at Dresden and elsewhere, is placed under one of the rails, which is built in two parts with the slot between them. The conductors in this case are of fairly heavy angle iron, one on each side of the slot as before, and the collector carries two contact pieces, generally of cast-iron, pressed outwards against the conductors, with a block of insulating material between them.

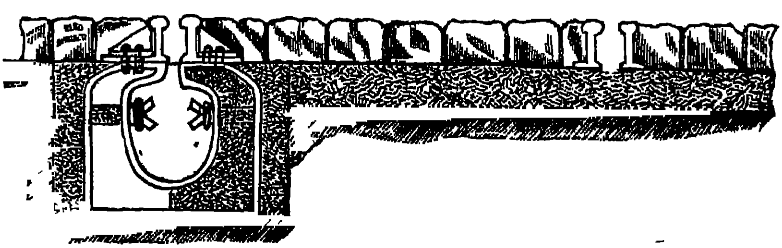


Figure 4.—Siemen's and Halske Conduit

As already remarked, Madras began with a conduit system, using the earthed rails for a return, but it did not prove successful and was abandoned in favour of the overhead system eventually. The chief troubles were excessive interference with the telephone service and the submarine cable companies, on which I shall offer some remarks another day.

Quite recently it has been decided to instal an extensive system of conduit tramways in London, the County Council being the operating party. The conduit, which is the design of Professor Kennedy, differs considerably from most existing ones, especially in two points—(1) that the yokes, whose function is to maintain the slot in position and in width, do not run also out to the rails as is usually the case, and (2) the insulators are supported from below and are not hangers as usually. This last detail has been much criticized as the protection from water and dirt will be less efficient. The system is not laid down yet.

Surface-contact systems.—We now come to the next class of work, where the energy is collected on the ground level, but *not* from a continuously-charged conductor laid between the rails. This latter method is dealt with under the next heading. There are two difficulties evident at the outset in surface work, namely, the danger of short circuits and that of shocks, and to avoid this difficulty many ingenious devices have been invented from time to time. The idea is to carry the mains underground, but to have contact studs at intervals or a conductor in short sections, from which the cars collect their current as they pass, these points being electrically "dead" at all other times. A large number of such systems have been described at various times, and a few are in actual operation. I have travelled on one—the Johnson-Lundell—in New York, and on another experimental one in Germany, and from the passengers' point of view they are excellent.

In the Johnson-Lundell system a bare line conductor in short sections is employed, this being laid between the rails and flush with the paving, the length of a section being approximately the length of a car. Each section of this conductor is energised in turn from the mains under the track by means of a magnetic switching device, the section being alive only while the car is actually over it, and the return being the ordinary rails. In this, as in most of these systems—and there are dozens—the car carries a battery sufficient to start the magnet

devices working at the beginning of a run, or if the circuit is accidentally broken at any time; but when once the apparatus is started its working is automatic, as the contact brushes on the car are arranged in such a manner that the circuit is not broken in passing from one section to the next; consequently, the line current is used to work the magnet devices. These latter are carried in switch boxes placed at intervals along the side of the track, each box controlling a considerable number of sections. Incidentally

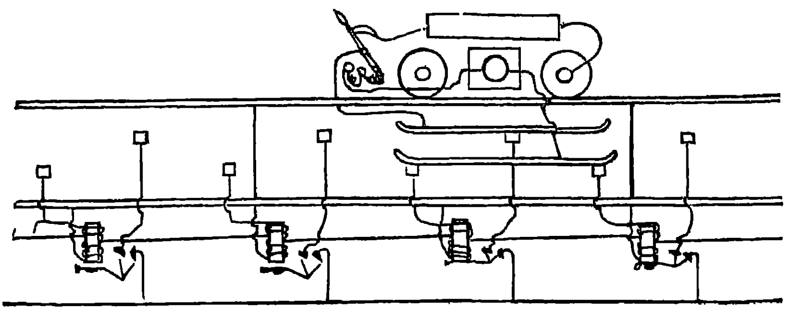


Figure 5.—Surface contact system.

it may be mentioned that the battery is used to carry the car over crossings and points, which avoids a considerable amount of complication. Figure 5 shews diagrammatically one such arrangement.

In the Thompson-Walker system—and indeed in the majority of the most recently-devised systems—the sectional conductor is done away with in favour of contact studs, a contact rail being carried on the car to conduct the current up to the motor, and arranged so that it rests on one stud before breaking contact with the last. As before, no more than two studs—and those directly under the car—are ever alive at once, so there is no danger of shocks so long as everything keeps in working order. The contact studs in this system are of phosphor bronze, and the collector, which runs nearly the whole length of the car, is of iron. Each surface contact carries its own automatic switch device, which is actuated as follows:—The phosphor bronze stud is only connected to the "live" line when the collector is touching it; when this occurs the current passes from the previous stud, through the collector, through the advance stud, through the magnetising coil, and back to the rail return. Now the coil magnetises an iron plunger, and this is promptly attracted towards the iron collector, and in doing so closes the "line" switch. As the car leaves the previous stud, the magnetising

current is broken, and the iron collector ceases to be over the plunger, so the line switch is opened and the contact becomes dead. As in the previous case, a small battery is provided for starting and to pick up a lost contact. An advantage possessed by this system is that the contact arrangements are very simple and can all be enclosed so as to be watertight; the moving plunger is entirely inside, and the stud is fixed—in fact, it is actually a part of the lid of the contact box. Hence it would appear unlikely that any switch should hold up when once properly adjusted. The switch has an auxiliary carbon break and is immersed in oil.

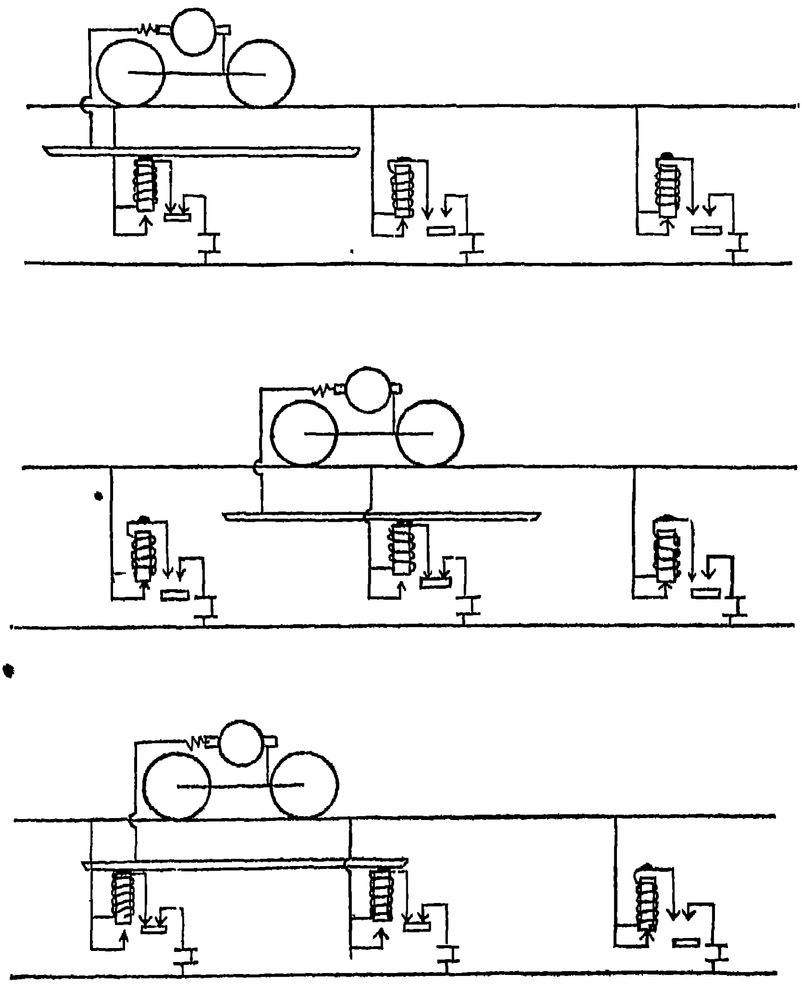


Figure 6.—Thompson-Walker system.

On the other hand, a 500-volt magnetising coil would take little to put it out of order if not perfectly insulated, and the small area of the contact is another obvious difficulty to be met with. There is not the same flexibility as with the trolley wire and pole, where the pressure is so applied that a break is most unusual. The conditions rather resemble the rail return, where even with four wheels making contact it is no unusual thing for a car to be sparking violently from jolting or from dirty rails. Of course, until such a system has had a trial extending over years to allow for the action of the weather on the parts and to ascertain the wear and tear and cost of renewals and so forth, it can only be judged on general grounds, but this one has all the elements of success in it for use in places where there is a fairly dry climate.

The experimental line I saw at Berlin was a combination of the two systems just described; contact studs were used and were energised from automatic switch pillars, each controlling a considerable length of track. I was able to watch the action of all the magnet coils as the loaded car ran, and everything went smoothly and well, but one could not help being struck by the great complication of having a separate electro-magnetic device to control every 40 feet or so of a large tramway system. It would not matter so much if occasionally a coil failed to energise its stud or its section, as quite a light and simple form of battery can be carried to take the car over such a short break; but if the failure of a coil can by any possible combination of ill-luck leave a section charged after the passing of the car, this would be a really serious matter—not in direct effect on human beings so much as in the indirect results of horses getting shocks and bolting.

The capital cost of surface-contact systems generally is intermediate between that of the conduit and overhead systems. It is doubtful if any other system than the latter will be used in India for many years to come, both on account of the low prime cost and of the simpler maintenance.

Third-rail system.—We now come to the system which, I believe, was the very first to be tried, but which for ordinary street traction has been entirely given up now, namely that in which both lead and return are laid on or close to the ground and remain charged throughout their length when in operation. Where there is no other traffic and no chance

of any unauthorized person getting on the track, this system has enormous advantages over others. The difficulty with it for ordinary work is of course that such bare conductors are inadmissible where there are pedestrians and animals crossing the track. Even if the pressure was as low as 100 volts, as has been proposed, it would be out of the question on these grounds alone, while the amount of copper required in feeders would be enormous and would condemn the scheme commercially. On the Giant's Causeway line in Ireland the third rail was raised to a considerable height above the road level, to which there is the additional disadvantage that it stops other traffic from crossing, and that system was changed in consequence of a fatal accident. For regular railways, however, especially elevated or underground ones, the objection does not hold good, and the use of the third-rail system is spreading greatly. In place of a copper conductor a heavy channel-iron conductor is used for the "line," supported at short intervals on special insulators, the insulating material being generally mica, I believe. Porcelain and glass are inadmissible mechanically, as strength to withstand jars is essential.

Elevated Electric railways.—On elevated railways, as distinct from those in the streets, these restrictions do not hold good. The public are not able to get on the lines, and the employés will take care of themselves. Much higher speed can be employed, and in place of a single car a train can be run. It will not be possible in the time at my disposal to say much about this branch of the subject other than in the way of general remarks. In the matter of elevated railways there are examples in many American cities, in Liverpool (the pioneer of electric elevated lines), and in several continental cities. The plan is to have the railway supported on a steel structure usually over part of the roadway, often bridging over the top of an ordinary road tramway. In this way the ordinary traffic is but little interfered with, and especially level crossings of road and railway are done away with. Fixed stopping places and stations are a necessity, and with short stops and rapid acceleration small trains and a frequent service, an enormous amount of traffic can be dealt with. The third rail is generally placed in between the other two, though sometimes outside them, supported on special insulators designed to stand the heavier strains which are entailed by an arrangement

thus lacking in the flexibility of the trolley wire. The contact shoe is arranged to have a large area of collection, since the plain-rolling line contact of a trolley wheel would be insufficient. A sliding shoe is generally used, hinged so as to quickly take up the slight unevenness of the rail. The rails and the whole structure can be utilized for the return circuit, so that there is little possibility of any leakage to earth taking place, though bonding of all parts is necessary.

Another form of railway which may be elevated is the monorail or single-rail system. Of necessity this single rail must be above the level of the passengers, in order to secure equilibrium, but the whole structure with the cars need not be elevated. Such an arrangement is, however, adopted in the Barmen-Elberfeld Railway, a peculiarly interesting line, which I recently went over. If it were not several miles in length, one would consider it as simply an experiment, and it is hard to see how it can ever pay. The train here is suspended bodily underneath the steel structure, which spans right over the road and for some distance over a river also. The motors and wheels are alone over the rails, the car being hung from them in a manner at once free from danger and yet allowing a ceitain amount of swing on curves.

Underground railways.—In London at the present time there are a large number of "tube" railways either running, under construction, or contemplated. These have the great advantage of not interfering with other traffic or with the roads and their contents in the way of pipes, etc., for they run far below all the other existing railways and sewers, some 70 to 100 feet below the surface.

The tunnels are generally constructed by means of the "Greathead shield." This is forced forward a little at a time by hydraulic pressure, the earth, etc., being continuously removed and the tube built up in sections following closely on the shield. At the time I was in England I visited one of these tunnels under construction, the point of working being actually just in the middle of the Thames. Owing to the nature of the ground, the work could only be carried out under considerable pressure, in order to keep the water out; it was about two atmospheres, or nearly 30 lbs. on the square inch above the air pressure, varying with the state of the tide. The air under pressure is constantly pumped in from engines on a pontoon up above, being led down the main shaft and in through double air-locks. It then escapes through the

gravel, etc., at the point where the shield is working, and can be seen from the bank bubbling up in mid-stream.

The "tubes" are built almost exactly the size of the carriages, the clearance being only a few inches. Amongst

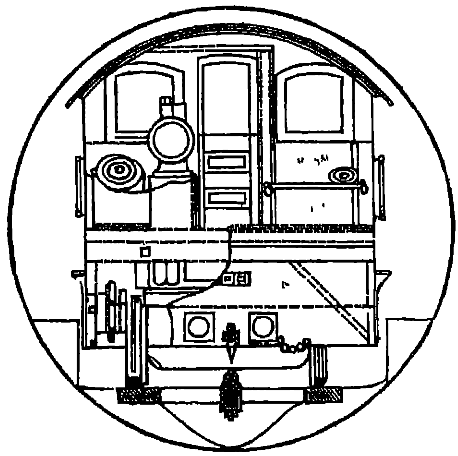


Figure 7.—Section of Central London Railway tunnel

other things this improves the ventilation. They are of cast-iron or steel, each complete ring being built up of about half-a-dozen segments bolted together, and to the last ring, and adding about two feet to the tunnel. They almost entirely fill up the space formed by the excavation, but what is left is grouted up under still higher air pressure; so one would think no subsidence or settlement could possibly take place on the surface of the ground some 80 feet or so higher up. But it is said—and no doubt it is geologically true—that the ground is in a perpetual state of slow readjustment, which is liable to be interfered with by the forcing through of a tube. A more certain danger is that the underground water-courses may to some extent be interfered with if the tube happens to cut across them. If they are known to exist a drain can be laid, and there is no interruption; otherwise the water is bound to take another course, and may take an inconvenient one. But when all is said, the amount of proved damage to buildings from any cause connected with tube-railway construction or working is very small up to the present.

No other system than electricity or compressed air is feasible in such a case, and the latter as a motive power has not proved financially successful. In these tube railways the third rail is always used, and the rails are used as the return. There are special regulations in force in England dealing particularly with the rail return; it is specified that it must either be connected to the tube at intervals not exceeding 100 feet by a copper conductor of at least $\frac{1}{10}$ of a square inch area, or else that it must not be so connected at all, except indirectly by the negative terminal of the generator being connected to both rail and tube.

Another and totally different form of tunnel for underground traction is the cut-and-cover, the street being opened up a little at a time, the tunnel in the form of a huge open culvert being prepared, and then the whole being roofed in by girders and the road made good for the ordinary traffic. These tunnels are now coming into extensive use in places where they are possible, that is, where the roads are not already a mass of pipes and wires which would have to be shifted. In Berlin I saw under construction a railway partly on this plan and partly overhead, its peculiarity being that no part of it ran on the street level at all; a long inclined plane leading from the one form of construction to the other. In London also it is now proposed to utilize this method of construction, though enormous difficulties must be encountered owing to the maze of wires and pipes and sewers already laid.

Locomotives and Motor trucks.—Now on these electric railways there are two methods of arranging and propelling the trains. Either an electric locomotive may be used to draw a number of carriages as with a steam-engine, or each car may be an independent unit capable of being run either singly or in combination with others. In this case each car has its own motors and starting gear and brakes, but in order to make safe running possible the whole is controlled by the front driver from a master-controller. The advantages of the latter course are that every car helps with its own motive power and with its own weight and adhesion, which enables more rapid starting, acceleration and retardation to be effected, while reducing the amount of dead weight to be drawn. Both systems have been considerably used, but the general consensus of opinion seems to be coming in favour of the multiple-unit method except in such cases as underground mining railways. The London tube railways started with loco-

motives, but they have recently been experimenting with the newer arrangement owing, in this instance, to alleged vibration troubles. Obviously there must be far more shock and jar with a locomotive having a concentrated weight of from 10 to 25 tons than with several separate motor trucks spread over a much greater distance and weighing only 5 or 6 tons each when loaded. In most of the electric locomotives on existing lines for passenger traffic gearless motors have been used, the speed allowed being sufficient to warrant the disuse of gearing. In some cases the armatures have been actually wound direct on the axles, but that subjects them to such rough usage, and causes such violent hammering at rail joints that it is better and more usual to put in a flexible connection and have the machines spring supported.

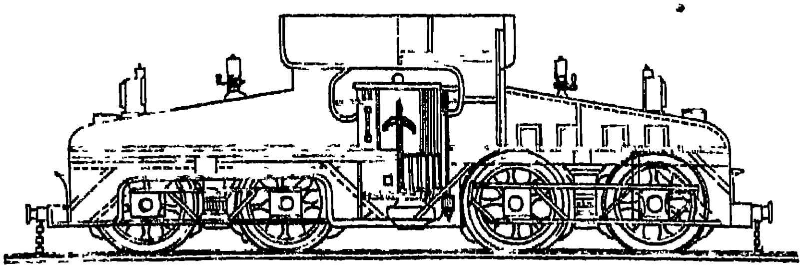


Figure 8.—Electric Locomotive (Central London Railway).

Figure 8 shows a characteristic electric locomotive of the type used in the Central London Railway. An end view of the same has already been given in figure 7. The data of this locomotive are given by Dawson as follows:—

The wheel centres of the truck are ...	5′ 8″ and 6′
Distance from centre to centre of trucks...	14′
Number of driving wheels ...	8
Total number of wheels	8
Diameter of wheels	3′ 6″
Total wheel base	20′ 9″
Do. length of locomotive	29′ 8″
Do. height „ „	9′ 8¼″
Weight on each wheel, about ...	5½ tons.
Total weight of locomotive „ ...	48 „
Drawbar pull	14,000 lbs. (6·2 tons).
Ditto running at 22 miles an hour	8,000 „ (3·5 „).

The weight of each locomotive will be about 45 to 48 tons. There are four gearless motors, *i.e.* one on each axle. The weight of the frame and coils of each motor with field coils in place will be 8,500 lbs., making a total weight for the motor of (say) 11,500 lbs. The driver's cab is fixed in the centre of the locomotive, giving him a capital look-out both ahead and astern. In the space over the trucks are fixed resistance coils with a passage way between them, the whole being enclosed by a sheet-iron cover. Instruments are carried, so that the driver knows what pressure he is getting and what current he is taking at any time.

LECTURE II.

THE OVERHEAD SYSTEM.

Aërial lines.—An aërial line is by definition in the rules (see Appendix I) "any electric supply-line which is placed above ground and in the open air." In the early electrical days aërial lines were largely used for electric-lighting purposes all over Europe and America, and they still have an enormous application in that connection, especially for long transmission and for distribution in scattered districts, and for use in climates such as India, where underground cables do not stand well. But it is for electric traction that overhead construction is of the most vital importance, especially as regards street tramways and railways, of which by far the great majority use the overhead system. It is now generally recognised that it is commercially the best to adopt, both for low cost of construction and for convenience of working. It is not that the whole or even the greater part of the conductors are placed overhead, but the working conductor in the vast majority of cases is. At first there was a great outcry every time the introduction of such a system was proposed, but the public, and even the local authorities, have now settled down and accepted it as a necessary evil.

In 1892-93 a Joint Select Committee of both Houses of Parliament met to consider many questions of great importance as to the effect that electric tramways, as usually constructed, would have by leakage and induction on other concerns, and some of their conclusions, on which I shall have something to say presently, are printed in Appendix II. The Committee were not intended to go into the question of the use of overhead wires, but of course that question was bound to play a prominent part in the proceedings, and one of the conclusions arrived at was "that the Committee regards with apprehension a large extension of the system of overhead wires in crowded centres." But neither this nor the distress of people who believed the beauty of a place would be hopelessly ruined and rendered unsafe for habitation, nor the still more acute distress of the advocates of other systems could stay the tide. Yet there was a good deal of truth in the complaints in those days, for the early overhead tramways in America were not only an eyesore, but a considerable source of danger, and it is well that the English Board of Trade all along insisted on thoroughly good construction, even though this put us somewhat behind other nations as to the number of miles of track

laid. When once it was clearly seen that the trolley-wire method had come to stay, our American friends accepted it at once, and the progress of the system was phenomenal, so that now about nine-tenths of their street railways are electrically worked. Several of their towns actually have a mile of tramway to about every 600 inhabitants!

Varieties of overhead electric traction.—The common feature of overhead systems is that one conductor is run in this way, the current being collected for conveyance to the motor by a device called a trolley. There are some cases where two separate overhead trolley-wires are provided for the line and return, but this leads to considerable complication and has not been widely adopted. The idea of course is that by eschewing the use of the earthed return, all the complications of induction and electrolysis are eradicated and the insulation of the whole system is increased, which is perfectly true. I refer here to continuous current traction; for in a three-phase system there are necessarily two insulated conductors as well as the third, which may be earthed or not. At Cincinati, where the double trolley was used in consequence of the opposition of the telephone concern to an earthed return, it has been found so difficult to arrange for the insulation of both trolley lines that it is stated that the car lamps can be lit up from one line and the rail, despite all endeavours to exclude the rails, as conductors. There are also difficulties at crossings. In the majority of cases, however, the return is by what the Joint Committee I referred to call "an uninsulated metallic return of low resistance," *i.e.*, the earthed track rails. Now a steel rail of heavy section has a great current-carrying capacity in itself; but as it is laid necessarily in lengths and not continuous, there are the joints to consider. From ordinary railway construction the best methods of making these to withstand the weight and shock they are subjected to have long been evolved, but the bolting together of the sections by means of fish-plates is not sufficient to give the joints good electrical conductivity, since the surfaces very soon rust up. This necessitates *bonding* by means of copper pieces at each joint, which I will explain to you in due course, or *welding* to make the rails continuous.

Overhead system with rail return.—We come, then, to this most widely-adopted system, and will shortly run over some of the main points about it before going into details. The trolley wire may be carried in several ways: centre pole

construction, where the poles are erected between the lines of a double track with brackets on either side carrying the trolley wires more or less over each track; side-pole construction, with long brackets projecting out over the single or double track, as the case may be; span-wire construction, where the trolley wire is hung from a network of steel-bearer wires carried on poles out of the way of the traffic. In broad thoroughfares, with the lines in the middle, the first method is perhaps most generally adopted, as by marking the centre of the road, it assists in regulating the traffic, and the poles can be used to carry arc lamps or clusters of incandescents. In narrow streets the use of a centre pole would still further diminish the width, so it is usual either to use side-poles and long brackets when the track is near the edge of the road or the span-wire method of support when the track is in the centre. At crossings and curves and in large open spaces the last method is the most usual. For taking the current from the line into the car the arrangements are placed on the roof, consisting either of a "trolley wheel" pressed up against the trolley wire and carried by a long arm or "trolley pole," with a powerful spring or a metal bow. Inside the car the current is first taken through the cut-out or circuit-breaker, then to the controller, thence to the motor, and to the return-rail circuit through the car frame and by the wheels of the car. A diversion is made for the purposes of lighting and heating, lamps being run in a series grouping over the full line pressure. In each car a lightning arrester is placed, and not infrequently an energy meter also. Each of these matters will need some remarks in turn. Then, finally, there is the generating station and all its adjuncts. We will take these all in succession, beginning with the track, then the feeders, then the line, next the cars, and finally the generating station.

Track Construction.

Foundations, rails and ties.—In the United States the road bed is usually of ordinary railway ballast, whereas in England it is more usual to use concrete alone where the nature of the ground allows it. About six to eight inches of well-laid cement concrete are necessary to make a firm bed. In such cases it is sometimes the practice to interpose some durable but elastic material between the rails and the concrete, special care being taken to adopt means to absorb the "hammering" at the rail joints. This has been recommended in several recent installations.

Of rails there are three main types which have survived of many introduced at various times; the Tee rail as used in railroad construction proper, which cannot be used alone for street work without detriment to the ordinary wheeled traffic, though when sunk flush it is greatly used in the United States; the step girder, and the grooved girder. The last, varying in weight up to 100 lbs. per yard, is used in by far the greater number of British tramways, since when properly laid it does not make any appreciable obstruction on the roadway, and the groove is too narrow to catch other wheel rims. The step girder rail is generally used in the United States; it may be either centre-bearing or side-bearing as shown in the illustrations, and it varies from 4 inches to $8\frac{1}{2}$ inches in height and from 40 lbs. to 100 lbs. per yard in weight.

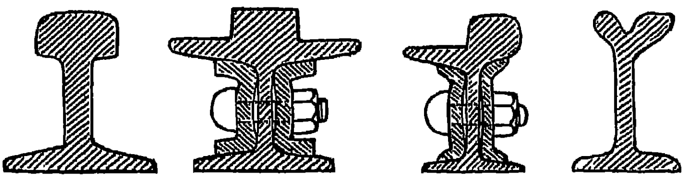


Figure 9.—Sections of Tee rail, centre and side bearing girder rail, and grooved girder rail.

The rails in America are generally fixed to sleepers or ties, as is also the case in British railway practice, but the modern tendency with British tramways is to lay the grooved girder rails direct on the concrete bed, using high rails with a broad base, which are good both from their stability, their large conducting area, and the fact that the ordinary granite setts or wood-paving blocks can be used between them without being cut shallow.

No doubt in this last form of construction the rails cost more money; but money spent on making the construction as solid and permanent as possible is always well spent. Track repairs on a badly-laid system swallow up all the profits, and it is obvious wisdom to increase capital cost where by so doing the regularly-recurring maintenance charges are reduced.

There is no question that the tractive effort required is greater on grooved than on step rails: it has even been stated to be as high as 40 per cent. greater, but the amount depends on the laying of the track and its freedom

from grit when laid. If the distance between the grooves, for instance, is not extremely uniform, a large amount of friction and wear is inevitable; but with a track laid as it should be, with the utmost care, this should not amount to much, and the lack of prejudicial effect on the wheels of passing vehicles gives a strong claim to the grooved rail. Whereas wooden sleepers have generally been used in railway construction, steel ties are largely used in India for the same purpose, and for use with grooved tram rails they bid fair to oust the sleeper altogether, as they serve also

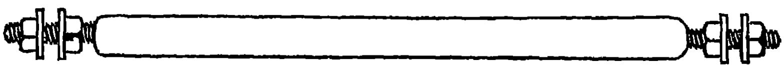


Figure 10.—Steel tie-bar.

to hold the rails strictly to gauge. They consist generally of flat bars about $1\frac{1}{4}'' \times \frac{1}{2}''$, forged circular at the end to carry $\frac{3}{4}''$ nuts on either side of the web (see figure 10). In these cases too the iron chairs on which so many types of rail are supported are unnecessary. For connecting together successive lengths of rail mechanically fish-plates are used, similar to those used in railway work, plates extending across the web at the point with two fish-bolts on either side of it. These fish-plates do not, owing to rust forming, serve to make the rails thoroughly continuous electrically, hence the necessity for bonding. In recent years many tracks have been electrically welded at the joints, instead of using fish-plates, and more recently still the cast-welding process has been tried with success. With both these methods, which I shall mention again presently, the rail becomes continuous, and how it is that expansion and contraction due to changes of temperature do not either distort the parallelism or snap the rails I am unable to fully explain. Every one is aware that in an ordinary railway track a space is left between the sections, and the rails are free to slide a small amount. It is equally certain that the gaps so left cause the hammer blows, which do so much damage; and that to do away with them would be of the utmost benefit to the carriages; and yet while all railways continue to allow for expansion, the whole arrangement is done away with in these welded tramway tracks. The general opinion seems to be that the strains set up by expansion and contraction are well within the limit of elasticity of the steel, and that the strains are taken up

by molecular change, which, on this theory, can go on indefinitely without damage, while no doubt the fact that the rails are buried greatly reduces the temperature changes to which they are subject. Where sleepers are used there is no entire consensus of opinion one way or the other as to supporting rail joints directly underneath or at a point on either side. The suspended joint must reduce the jolt considerably, but probably does not last so long.

Special rails, points, crossings, curves.—Points being subjected to greater wear than other parts are usually made of crucible steel. They are generally of a simple mechanism, worked either by a pointsman or on the spot from the car, and there are two common types. In the first there is a movable tongue on one rail, while on the other rail a fixed tongue is put sufficiently in advance to ensure the car having already taken up one side or the other; in this form a car can be diverted either way. The other usual form of switch is the automatic one used at turn-outs or sidings, when the facing car is always required to go on to one line and a trailing car to come from the other. The tongue is then spring held, and the car wheel pushes the tongue aside and compresses the spring to pass. At the frogs and crossings, where one rail crosses another, a steel casting is also generally used because of the greater amount of wear. The various books on electric traction give innumerable diagrams of the arrangements at switches, crossings, etc., and there is not time for me to go into these in detail. Most of them can be studied in the streets of Calcutta or on the Kidderpore line at the present time.

Owing to the greater speed and weight of electric cars curves have to be laid out with very much greater care than is the usual case with horse traction. Practice differs considerably according to the conditions of the roadway and the other traffic on it. It is always desirable, but often impracticable, to raise the outer rail according to the proposed speed and the sharpness of the curve, as on railway lines. The take off from the straight rails is the point where the greatest care has to be exercised, and it is ordinarily inadvisable to make the curve circular from this point, owing to the strain that would be thrown on the car. The line must of course be a true tangent to the first portion of the curve, but this is arranged to increase its curvature gradually by means of a spiral transition curve, the middle piece only being an arc of a circle. As an example figure 11 may be examined. Such a spiral as this, or a part of it

only for curves of large radius, will ensure a car always entering the curve at the same rate of change of direction.

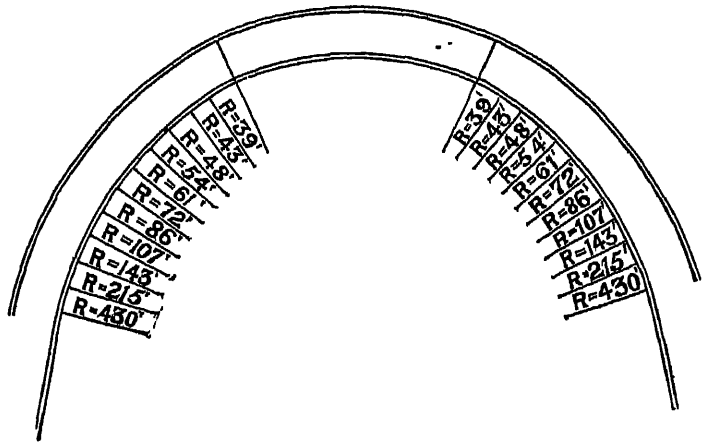


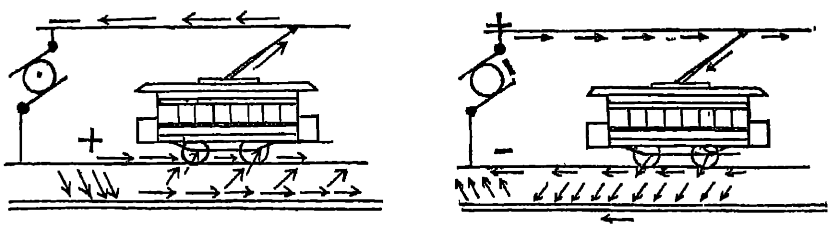
Figure 11.—Spiral transition curve.

Another point is that on double-track curves the outer track is struck from a different radius, so as to give greater clearance between the cars than suffices on the straight. The gauge of the rails, too, is often widened somewhat in order to reduce the strain on the wheels, but with grooved rails the amount must be extremely small. In the latter case, however, another method has been successfully tried, *i.e.*, having the grooves themselves wider on curves, so as to reduce the wear on the flanges and, in the case of the outer rail, having a very shallow groove. The effect of this last point is that the outer car wheels take their bearing on the flanges and, having larger peripheries, travel over more ground per revolution, thus reducing the amount of "marking time" to be done on the inner wheels and the consequent wear. Another recent improvement is the drain rail, arranged for carrying off the water as it falls. It is said to save its cost in a very short time, but in dead flat places it will not have the same application as elsewhere.

Rail returns and Bonding.—Bonding is, as already stated, necessary in order to reduce the resistance of, and the drop of potential on, the earthed rail return. The rails themselves are invariably of heavy enough cross-section and good enough conductivity, but it is the joints that are not so. If a large drop is allowed, there will be excessive damage to the metallic bodies in the neighbourhood,

as was the case in the early days of electric traction in America.

At the present time it is the universal practice to connect the positive pole of the generator to the line and the negative to the rail return, as this confines the tendency to damage from electrolysis to the rails themselves, the lead sheathing of the return feeders, and the pipes, etc., in the immediate neighbourhood of the station. Each of these can by proper construction be protected almost entirely. Electrolytic corrosion takes place at the point where the current leaves the pipe or rail: at the point, that is to say, which is positive to the earth. Now, if the positive pole of the generator is connected to the rails and to earth, the tendency is for a considerable proportion of the current to take the earth path near the power-station, to run along the water and gas pipes, and to leave them for the rails again at all points where cars are running near them, thus causing corrosion over a wide area (see figure 12.)



Figures 12, 13.—Diagrams of earth return currents.

If, on the other hand, the rails are made negative at the generators (as in figure 13), the tendency is for the general leakage to be from the rails (which will suffer corrosion) to all the pipes along the track, which then carry the current to the neighbourhood of the power-house, where it leaves them again to get to the generators; and if at these near points copper conductors are run to the pipes, they will take the current back and prevent it going to earth and causing corrosion even near the power-house. But even so, if the leakage is not very small, corrosion will occur at every separate joint in the pipes, where the resistance is naturally much higher, the current taking an earth-path round the joint (see figure 14). The figures are adapted from Dawson's "Electric Railways."

Where gas and water mains run near one another, there is a tendency to leakage from the gas to the water-pipe if

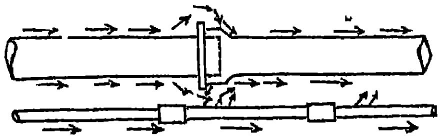


Figure 14.—Currents in gas and water pipes

both are carrying current, the resistance of the joints being higher in the former.

I have already mentioned the fact that a Joint Select Committee of both Houses of Parliament threshed out this whole question in 1892-93, and that as the result of their deliberations, after hearing a great number of witnesses representing all interests, was embodied in a clause which has since been included in all English documents authorising electric traction other than by self-contained cars. Evidence was taken from the officials of the Post-office, on behalf of the telegraph system; from the Board of Trade, who control electrical undertakings of all sorts; from the Astronomer Royal, with regard to interference with magnetic observations; from representatives of the Telephone Companies, the Railway Companies, the Electric Tramway Companies, the Electric Lighting Companies, the Gas Companies, the Water Companies, and the Municipal Corporations; the last three as owners of extensive systems of underground pipes, which might be adversely affected. The reference to this Joint Committee was "to consider and report whether the grant of statutory powers to use electricity ought to be qualified by any prohibition or restriction as to earth-return circuits, or by any provisions as to leakage, induction or similar matters; and if so, in what cases and under what conditions."

Now, the general conclusion is summed up in their Resolution, which subsequent events prove to have been a most wise and far-seeing one, that "the Committee, having regard to the evidence before them, are of opinion that it is not in the present state of electrical science to the interests of the public to insist upon electrical tramways using an insulated return conductor, and that such insistence would retard the development of electric traction."

They also saw that, in the interests of the public—and equally, in the long run, of the undertakings themselves—rules were necessary to prevent the continuance of the early troubles, and the third sub-section of their now famous clause provided for the issue of such rules. These rules will be printed in full at the end of these lectures in the form in which they have been adopted by the Government of India (see Appendix I), and I will call attention to the general result in a subsequent lecture.

Methods of bonding.—Now the result of the rules is that the utmost care must be exercised in laying down the track if it is to pass muster after a few years of working; that is why I said that the rules operate to the good of the undertakers as well as of the public, for a badly-laid track is a source of continual heavy expense in maintenance. This brings us to the question of bonding. A bond is usually a length of solid or stranded copper electrically connecting two rails together—apparently a simple enough process, but one which in practice required some years before it attained even approximate perfection.

The use of the bonds is to make up the conductivity at the rail joints, where it is naturally bad, as fish-plates rust up in no time. Not only is each rail thus to be made electrically continuous, but the various rails all need to be occasionally cross-bonded. The mere bolting of a copper strip on each side of a rail joint is not sufficient, for rust will soon introduce great resistance at the contact, and much ingenuity has been displayed in inventing good bonds. The most usual plan is to have an extra hole drilled in the web of each rail, just beyond the holes for the fish-bolts. When the rail has been laid and fitted mechanically, these holes are reamered out to obtain a bright surface, and the ends of the bond are cleaned and inserted in the holes and expanded to make the most intimate connection. Where points or crossings come in the bonds are usually made to run from rail to rail round the special piece, and in such cases the bond is preferably flexible. The same remark applies to bonding from track to track, which is done at all crossings. A bond may be anything over one-sixteenth of a square inch in cross section, half inch diameter being the approximate size in Calcutta. The ends here consist of a hollow thimble, which just fits into the hole in the web; a bullet-shaped pin, slightly larger than the hollow of the thimble, is then driven

into it, which forces the copper into close contact with the steel. After the bond is fitted it is coated over with pitch or some protective paint, and in this way air and water are alike excluded. The figure shows a similar bond—

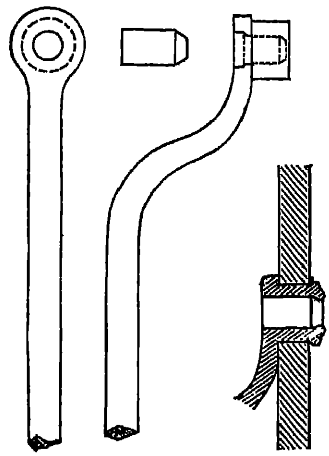


Figure 15.—Chicago Crown Bond

There are various forms of bond in use, though this would appear to be one of the best. Another good bond is the Columbia, shown in figure 16. It consists of three pieces, which is generally considered a disadvantage, as entailing more chances of a bad contact, but when fixed it virtually becomes one piece. In each web a hole is drilled and a hollow copper thimble is inserted, tapered inside and out in opposite directions. The bond is a copper rod whose ends are conical to fit inside the thimbles; it is placed in position, and then pressure is applied to force it against the cone and the latter against the web, the head being practically riveted on both sides.

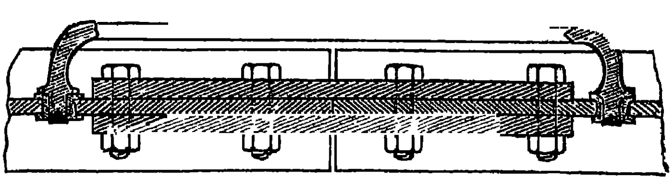


Figure 16.—Columbia Bond.

I will mention one other on a different principle altogether, known as the plastic bond. In this case the idea is to use the fish-plate also as a bond by preventing the formation of rust between plate and rail; the surfaces are cleaned up and

a plastic alloy or amalgam is placed between them, which spreads out under pressure of the bolts and makes a good electrical connection. This plastic bond is widely used in some countries not only for rails, but also for bus bar connections, as an improvement on the use of tinfoil for increasing the area of contact.

Where the conductivity of the rails alone, when bonded, is not sufficient to keep the drop of potential within the prescribed limits, a supplementary return conductor of copper used to be laid either between the rails or between the tracks. When so laid it must, by rule 56, be electrically connected to the rails at intervals not exceeding 100 feet; and as all the rails are part of the circuit, a conductor of the same size as the bonds generally sufficed. The use of these supplementary wires has now been given up entirely in favour of more careful bonding and return (insulated) feeders.

It follows that if any single bond breaks or loses its good contact resistance is promptly introduced, which shows the importance of using the utmost care in the process of construction. For ascertaining the condition of the bonded rail joints, an instrument is used consisting of a low-resistance voltmeter and two contacts, which can be pressed on the rail on either side of a joint. If there is any considerable drop of pressure owing to bad bonding, the rail-tester will show it, and by comparing a length of solid rail, whose resistance is known, with a length containing a joint, the resistance of the latter can be calculated. To do this accurately either simultaneous readings must be taken on two instruments or a number of readings must be taken to ensure an average equal current for both rail and joint.

Continuous welded rails.—Without attempting to go deeply into this subject, which is treated in many books, I may say here that the usual methods of making a continuous rail are two. In ordinary electric welding a special welding machine is run on the track, taking its current from the line. By means of a motor-generator the line current is converted to alternating current, which is then transformed down to an output of about four volts and capable of giving 40,000 ampéres. This is applied at the rail joint, which with its fish-plates is first cleaned by a portable emery wheel, and each rail is in turn welded to the fish-plates by heating to a white heat and then applying great pressure. In some cases the rails themselves are preferably welded direct, without fish-plates. The space existing between the abutting rails, if

any, is filled by driving in a thin section of rail first. The second method, or cast-weld, is perhaps hardly a weld proper. The process is to clean the abutting ends of the rails with a portable emery wheel and then to pour a large weight of molten cast-iron around them, using a mould for the purpose. This cast-iron unites with the rail ends and offers a very large cross section to the current (see figure 17). About 120 lbs. of metal are used at each joint, this being carried along in a large cupola capable of holding enough metal for a number of joints. There is no actual weld between the cast-iron and the steel, but the rail is brought up to a great heat, and the intense pressure set up forces the two metals into the most intimate contact, so that, in a joint sawn through, the cast-iron seems to have actually bitten into the steel. It was recently stated in the *Electrician* (September

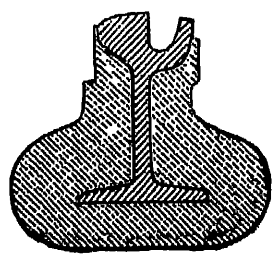


Figure 17.—Falk cast-weld.

13th, 1901) that in one continental installation, where continuous rails were used, 10 per cent. of electrically-welded rails proved faulty, but that the cast-weld joint had proved better, and only 3 per cent. were bad. Even this proportion is high.

Feeders.—We have already seen that feeders are the mains used to conduct energy from the generating station to the distributing points. The trolley wire itself cannot be of sufficient size to carry the current required for all cars without far too great a drop of potential, and, apart from this, it must be divided up into sections of half a mile electrically independent. So feeders of large size are run also, and are connected to each section of the line in turn. The case is different from lighting feeders, in that the same feeders in tramway work will often serve a number of sections of the line, not at one single point only; wherever these connections are made (see figures 18 to 20) a pole switch is inserted and also a lightning arrester. What is required is to keep the maximum drop and

the average drop between certain defined but fairly wide limits. In a properly designed system this use of feeders ensures all sections getting approximately the same operating pressure within these allowable limits. It is not necessary on the feeders and insulated line to keep the drop down nearly as low as on the return, since it is determined by considerations of prime cost, cost of energy wasted, and proper operation of cars—economy in fact—there being no necessity for rules to regulate it in the public interest, as in the case of the uninsulated return or of electric-light feeders, where a large drop affects in the one case the pipes of other parties and in the other the standard pressure received in the houses.

Methods of arranging feeders.—The different ways of arranging feeders are many. The first method adopted was to have a feeder run in parallel with the trolley wire and connected to it at frequent intervals, which was virtually equivalent merely to increasing the size of the trolley wire. The line could be broken up into sections (see figure 18) or not, but in those days generally was not.

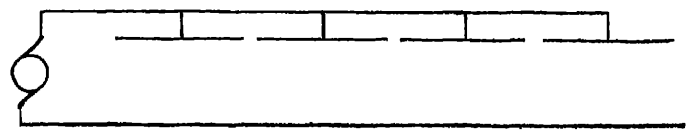


Figure 18.—Single feeder connections.

A far better arrangement is that shown in the next figure, which is a true feeding system, though in the simple form shown it would scarcely do. Here the line is divided into

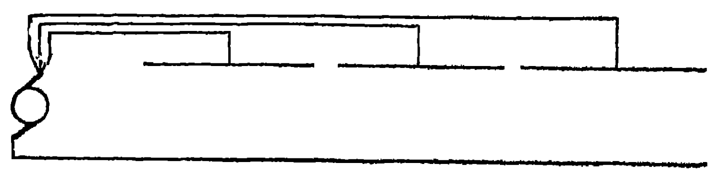


Figure 19.—Feeders to various points.

sections, and a feeder is run out to each from the generating station. By properly proportioning the feeders, this arrangement will give a fairly uniform drop. But with a system divided into half-mile sections, the number of feeders would be altogether prohibitive, and a modification is necessary by which each feeder supplies a considerable length of trolley. In fact, these main feeders are used to supply

subsidiary feeders, which in turn supply each section of the trolley line (see figure 20).

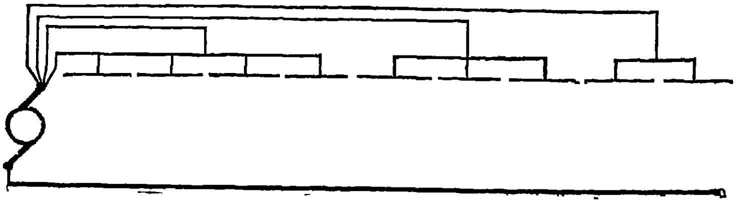


Figure 20.– Main and subsidiary feeders.

Arrangements can be made by which two feeders can be joined up in parallel to reinforce one another at particular points when occasion demands it, as at *a* in figure 20—in cases, for instance, where a very heavy local demand occurs at particular seasons of the year.

It is impossible in the time at my disposal to go into the question of the design of a system of feeders: it is a complicated process, requiring a thorough knowledge of the conditions obtaining. While on the one hand in a simple system there are just feeders which run from the station and are tapped off to feed each half-mile section of the line, in other and more complicated systems these are arranged to do this from certain central points to which main feeders are brought from the generating station. Taking the former case, the size of feeders depends on the drop in volts which is to be allowed and amount of current to be transmitted by them, and that in its turn depends on two factors: the nature of the ground—whether level or having steep grades—and the number of cars likely to be on any section at one time. This last factor depends on the speed and the headway, or time interval between any two cars. The drop usually allowed is from 10 to 15 per cent. on 500-volt systems, this being the standard pressure in British practice. The very roughest estimate of a feeder might be worked out on the ordinary basis of 1,000 current density, but this does not suffice for more than the first roughing out, for it may give far too high a drop.

In more complicated systems the method is long and tedious, and I would refer those of you who wish to know more about it to Louis Bell's "Power Distribution for Electric Railroads." The lines must all be laid out in a plan, and the "electrical centre of gravity" of the whole, and of each section must be found by reference to the number of cars running, etc., and the calculations involve the

consideration of the extent of lines, average load on each line, centre of distribution, maximum load, the method of feeding, the necessity for reinforcement of the feeders at any particular point, etc. All this is dealt with in the book referred to, and examples are given. (See also page 78 post).

On a level system of lines single cars of ordinary types may be reckoned as taking about 15 ampères at the usual pressure of 500 volts, or with trailing cars 25 ampères. On ordinary gradients a single car may be reckoned to take from 20 to 30 ampères according to steepness. A useful formula is given by Dawson for cross-sectional area of sub-feeders:—

$$CM = \frac{C \times K \times D}{V},$$

where CM = circular mils ($\frac{1}{1000}$ inch) of cross sectional area,
C = Current,
D = Distance to point of consumption,
K = A constant,
V = Volts drop in feeder.

Assuming an average speed of 9 miles an hour, 15 per cent. drop in voltage, taking K as 13 and allowing 25 ampères per car with headways up to seven minutes and 30 ampères above that, the following table is given by the same authority:—

Pounds of Copper required for Line Feeders.

Headway in minutes.	Length of track in Miles.									
	1·5	2	2·5	3	4	5	6	7	8	10
3	810	1,716	3,412	6,506	13,756	27,343	45,820	73,595	109,365	202,927
4	610	1,361	2,708	5,159	10,938	19,439	37,041	53,456	79,378	152,731
5	510	1,079	2,145	4 095	8,673	15,404	26,724	43,213	65,620	123,000
6	405	857	1,701	3,245	6,878	13,672	23,327	38,278	52,030	103,710
7	321	857	1,701	2,574	6,878	13,672	21,197	31,177	44,858	89,074
8	405	857	1,701	2,574	6,878	13,072	21,197	34,310	40,387	93,562
10	405	679	1,349	2,041	5,458	10,842	16,406	27,215	30,221	76,366
12	405	679	1,071	2,041	4,327	8,598	16,406	21,588	32,788	61,733
15	405	679	1,071	1,618	3,431	6,823	13,009	19,110	28,201	40,026
20	405	679	1,071	1,618	2,721	5,407	8,817	15,179	21,874	33,878

Feeders used to supply subsidiary or line feeders at a single point are calculated out, as in the case of electric-light feeders, by the so-called law of maximum economy, so far as it holds good. Several forms of this exist. Lord Kelvin's original statement was "the most economical area is that for which the annual cost of energy lost just equals the annual interest on the capital invested." Hopkinson's modification provides for the ratio of the gross annual revenue derived from the conductor to the total gross annual expenditure upon it and on the energy supplied through it to be at the maximum.

Laying of feeders—Feeders may be run either overhead or underground, according to circumstances. Where the low-tension feeders run from sub-stations, which are fed from a distant source at high pressure, the high-pressure feeders will almost invariably be run overhead; but for ordinary tramway work in towns, underground feeders are generally used. Personally I have grave doubts whether it will be found advisable to run any cables whatever underground in this part of the world, as the great majority give trouble after a year or two, but they are so run in most countries. Underground feeders for tramways are constructed and laid in a number of ways: the insulation may consist of vulcanised India-rubber, protected by braiding, etc., or lead, or paper protected by lead, fibre impregnated with oils or products of the nature of bitumen etc., etc. They may be laid either directly in the ground or in various forms of open or filled-up conduit. I will take a few out of many just as examples In my previous lectures I gave a short description of the Callendar "solid system" of impregnated cables laid in cast-iron troughs filled up with bitumen. A section of that troughing is shown in figure 21.

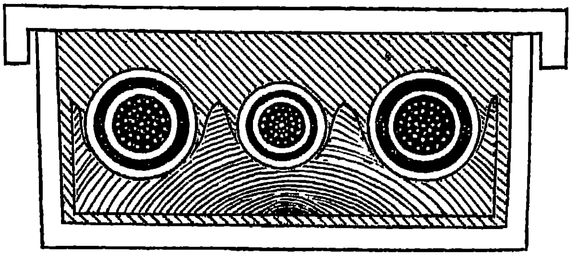


Figure 21.—Callendar mains (section)

The British Insulated Wire Company use chiefly paper insulated cables, lead covered, and also laid on the solid system with bitumen. The real insulation is in this case obtained from the paper and the dry air surrounding it, and it is quite essential to prevent any trace of moisture having access to it. Where cables are laid direct in the earth, they must be lead-covered and then armoured as a protection against mechanical injury. The armouring is of steel, in the form of tape or wire wound in two layers in reverse directions or in a special shaped section, which renders one layer sufficient by the strips overlapping and locking. Over the armouring is an impregnated covering to prevent rusting or chemical action from the soil.

Other methods consist in laying a pipe or conduit through which the cable is afterwards drawn. These conduits may be of cast or wrought-iron, of stoneware or concrete, or various other materials, and are made in many forms.

When these "drawing-in" systems are used manholes are placed at intervals for the purpose, and a light wire is used to draw the cable through. The manholes must in England have ventilating arrangements (though of course these must also be watertight) this being on account of the danger of gas accumulating in them and causing explosions. This is a danger to which all closed conduits are subject, and a good many such explosions took place before free ventilation was insisted on. The Calcutta feeders are all laid on the solid system in iron troughing.

Junction-boxes.—In electric-lighting systems there are very few feeding points, but in a tramway there are many owing to the necessity for dividing up the line into short sections. Between these sections there is an actual break of continuity only when the section switch is opened or the fuse has blown. The lines on each side are connected to the feeder in a junction-box with switches for each connection, these boxes being placed either on the pole or on the footpath. Figure 22 shews one arrangement for the electrical connections of the junction-box and the switches. The connecting wires from the feeders are, as a rule, carried up the inside of tubular poles, coming out near the bracket arm and running along it to the trolley wire where the connection is made by means of special feeder ears.

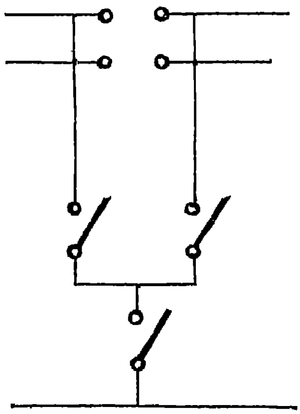


Figure 22.—Junction-box connections.

Lightning arresters.—At various points it is necessary to put lightning arresters also for the protection of the feeder and overhead line. In my previous lectures I described two or three forms, so I will now describe a different form used particularly in traction work. In principle it is not dissimilar to the ordinary telephone arrester, which consists of two plates of metal, with teeth at the edge, brought close enough together to make an easily bridged gap. But in such an arrester on a 500 volt circuit an arc would be formed which would continue to burn until nothing was left of the plates! Instead of getting over this difficulty, the Ajax arrester takes advantage of it in the manner shown in figure 23. Two No. 26 gauge brass wires, each insulated with a single covering of silk, are placed touching one another for about two inches, one connected to the line and the other to earth. On a discharge occurring over this very small spark-gap — $\frac{1}{500}$ inch—they are completely burnt up, and the arc is thus broken. A dozen of these fuse arrestors

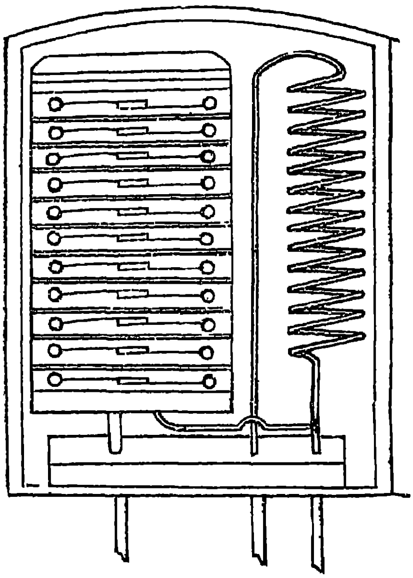


Figure 23.—Ajax lightning arrester.

are placed in a single case, and as the top one is burnt out, the next is automatically put in circuit. This is done by means of a carbon ball, which makes the contact between the line and its fuse by resting on the end of the connecting wire of the fuse and against a long U-shaped strip of metal

connected to line. When the fuse burns up with its connecting wire, this carbon ball is no longer supported, and consequently drops down to the next support below, putting it into circuit ready for action. A cast-iron water-proof box holds the set of arresters, with an asbestos lining to prevent the arc striking over to it. The box itself is always earthed in England, whatever type of arrester is used. As a rule choking or kicking coils are used to assist the action of lightning arresters by insuring the discharge jumping the air gap at the right point. Alternating and oscillating currents of high frequency will more easily jump a clear air insulated space than go round a coil having self-induction; so the alternative is offered, and the arrester is usually chosen. You will notice that in Calcutta the lightning rods are generally provided with an artistic coil of three or four turns at the top. Apart from the fact that the construction and fixing of these rods is so deficient in other ways, that they are entirely useless, it is doubtful whether a lightning discharge would ever traverse this unintentional kicking coil. Obviously these rods should run with as few bends as possible, and these quite gentle ones. Twists, zigzags and right angles are unnecessary and harmful. Such a coil offers no impediment to the ordinary direct current supply of energy from the feeders.

Money laid out on a carefully-arranged system of arresters is well spent, for should a discharge damage the underground cables, it will do much harm as well as perhaps stop the service. The trolley wire is the part most liable to be struck. Should a discharge occur at the rail, the series coils of the car motors will act as choking coils and preserve the machines from burning out.

LECTURE III.

The Overhead system—*continued.*

I have already mentioned that there are three forms of overhead construction, viz., centre poles, side poles, and span wires. We now come to the construction of this part of the equipment, and it has been a difficult matter with so much material at hand to know what to describe and what to leave out. We owe to the engineers of the United States the design of most of the details of the best modern overhead construction, even though in many instances our own people have improved on their designs in view of the somewhat different requirements of British practice. Our intense conservation always leads the majority of us to look with suspicion on new ideas radically different from those obtaining, other nations take them up and get a good start of us, and eventually the experience gained abroad is utilized by our own engineers, who are able to avoid the early mistakes and failures of our competitors.

Poles and Brackets.—These are almost always steel, of graduated tubular form, and of very stout construction owing to the severe side strains to which most of them are exposed; the bases are generally castings, as they have to be made heavy and very strong. Where feeder connections are made, the base of the pole is sometimes utilized for the connection. Built-up lattice poles could be made stronger and perhaps cheaper, but their appearance would be intolerable, and they have been very little used; in America both these and wooden poles have been used to some extent. For ordinary centre pole construction on straight runs, the pole can be comparatively light and erected vertically to start with. In span-wire or side-bracket work and on all curves it is necessary to give the poles a rake in the direction to oppose the pull on them, whether due to dead weight, as in the case of very long projecting side brackets, or to strain, as in the case of span wires and curves. In span wires and curves convex to the poles the strain is an inward pull, while on curves concave to the poles the dead weight and strain oppose one another, and the strain is the factor which must be reckoned with as the more powerful. Where span wires are used the strain is very great if the spans are large and the wires strained up tight, and a rake up to

one foot is sometimes necessary. The height of poles is regulated to ensure a minimum height for the trolley wire, in the centre of spans, of 17 feet, as prescribed by Rule 74 of the Government of India, unless of course lighting is to be done on the same poles (as is sometimes the case) in which event the height is altered accordingly. Spans may not exceed 120 feet under the same rule, and the trolley wire is generally strained up to give a maximum dip of about 15 inches in hot weather on the full span. On curves the spans are shortened, since the poles cannot easily be stayed laterally, as other overhead lines can, and the dip is proportionately reduced. One rule is to allow a dip of $\frac{3}{4}$ per cent. of span at the average temperature. Poles are set in concrete or in rammed earth and stones according to the nature of the ground, in holes from 4 to 6 feet deep, the base generally resting on a block of stone. Brackets are made of pipe as a rule, as castings would suffer from the continual jar and strain, and would be more expensive. For ordinary centre pole construction, nothing but the pipe is needed, and the scroll work generally used is for the sake of appearance; where a bracket projects over 6 feet, it is generally necessary to put in a stay rod from the top of the pole, and in the very long brackets used for side pole construction on a double track (figure 24) several stays are required, running out to

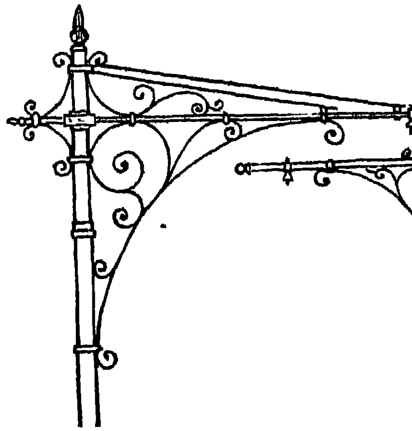


Figure 24.—Long side bracket.

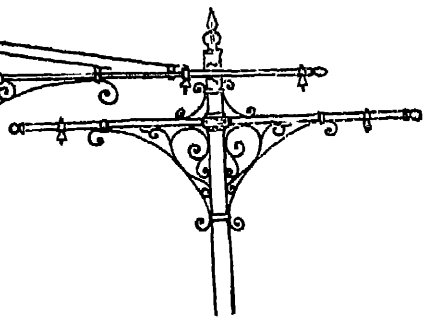


Figure 25 —Double bracket.

different points along the bracket. In many cases the line is supported, not by the bracket itself, but by a steel wire stretched between the pole and the end of the bracket. Such

a method of flexible suspension does away with a good deal of jar as the trolley wheel passes the poles, which at the high speed often reached is an important matter. In span-wire work stranded mild steel bearer wires are employed, hung from poles on both sides of the street. The determination of the correct amount of dip to allow on span wires is a somewhat complicated matter, especially on curves; but the main point is that the height of the trolley wire in middle of span must not be less than 17 feet at any time. The more extreme the cold and hot weather temperatures, the more carefully do the details want working out to avoid on the one hand excessive dip, on the other hand excessive strain.

The Trolley wire and its adjuncts.—Hard-drawn copper wire is almost always used for the overhead line as giving the best combination of conductivity and tensile strength, but in exceptional cases phosphor bronze has been used, which is enormously stronger while still having fair conductivity. The usual size of trolley wires is 1/0 S. W. G., diam. ·324 in., area ·0825 sq. in.; resistance ·099 ohms per 1,000 feet; weight 1,680 lbs. per mile: or 3/0 S. W. G., diam. ·372 in., area ·1087 sq. in.; resistance ·075 ohms per 1,000 feet; weight 2,210 lbs. per mile.

The wire has to be held in position over or near the tracks, and insulated from its supports, while at the same time the arrangements for holding it must allow the trolley wheel or collecting bow to run freely past. The wire is therefore soldered to grooved ears (figure 26) of gun-metal, shaped to fit the top of the wire accurately and ready tinned to receive it. The ears are held from above by the special

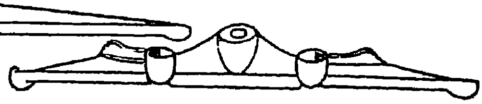


Figure 26.—Ordinary ear. Figure 27.—Splicing ear.

insulating devices about to be described, which in their turn are fixed to brackets or suspending wires. But in the case of bracket construction the system is somewhat rigid and apt to cause breakage, so the practice is often to suspend the ear flexibly, as mentioned above, on a short length of steel bearer wire hung between the end of the bracket and the pole with a span wire insulator.

Where the line makes a sharp bend, the side pull on insulators of the ordinary types described becomes very great, and there would be a danger of their pulling over—for they are built for vertical support, and not to stand side strains—and the jolt of the trolley wheel adds to this danger considerably; so in such cases two insulators are usually placed side by side; a gun-metal bar, about 8 inches long, is placed across and insulated by them, and the ear is fixed to the middle of the bar and bent to suit the direction of the trolley wire.

Where a joint is necessary in the wires, the ends are brought to a special splicing ear (see figure 27) arranged so that each wire is brought up through the metal, then turned back on itself, and soldered above as well as below the ear. Should the erected trolley wire break at any time, a special splicing tube is used (figure 28) to effect the repair, into which the two ends of the wire can be put while held together by a straining-up vice. The tube has slots in it through which saw-edged "dogs" can be slipped in, and these nip the wire as soon as the strain is relieved and

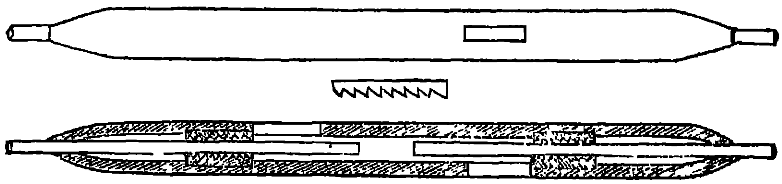


Figure 28.—Splicing tube.

dispense with soldering, while allowing the trolley wheel or bow to run smoothly across.

Special ears are also used where feeders come in, carrying terminals for the connections, and others again for anchoring the trolley wire at intervals. This anchoring is necessary because there is a tendency for the trolley wire to drag the ears away from the insulators, and much of this strain is relieved by occasionally staying the ears themselves, so that the point acts as a terminal. In case a breakage occurs, it cannot then affect the line beyond the nearest anchoring points. Four separate stay wires are run, two in each direction of the line, spreading out from the ear to the extremity of the brackets of the next pole, the insulation being obtained from the strain insulators I am about to mention. To prevent the brackets thus used from being

pulled over, the wires are continued beyond them for another span, and there fixed to the pole itself as low down as is consistent with safety.

For suspending the ears to and insulating them from the brackets and span wires, and for keeping them over the lines on curves, a great variety of apparatus has been designed. I only propose to mention a few pieces of which I have samples to show you. It must be remembered that the arrangements must be such as to allow the car to run safely past the supporting places, whether simple or complicated. This necessitates a design such as allows the trolley wire to be soldered to the lower side of the conducting piece, which is itself insulated from the supports of the line. The actual insulation is effected chiefly by two methods, viz., bolts encased in insulating material and uninsulated bolts screwing into a cap of insulating material. Porcelain and glass are not admissible for this class of work, as they would be unable to stand the continual shocks; so special compounds are made up which can be moulded or pressed into shape, and which retain sufficient elasticity to stand a great deal of hard wear when protected by a metal covering. Hard India-rubber is employed in some cases, and compressed mica, similar to that used for generator brush-holders, is also very largely used. The exact composition of the material is, however, more or less of a trade secret.

Figure 29.—Aetna Insulator.

Figure 30.—West-End Insulated Bolt.

In the case of the metal-capped insulators, the conducting ear is screwed into the insulation, which has a threaded metal liner in it. In the other case the insulated bolt can be screwed down on to the conducting ear, which can therefore be soldered previously to the line. The bolt runs inside a complete cast-metal case, which holds the head of the bolt, and a cap is screwed on the top, so that its insulating covering is completely protected from injury; and even if the insulation is totally destroyed, the bolt head is still held

and the line cannot drop. Illustrations are shown of a few typical parts using the "West-End" insulated bolt.

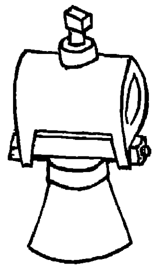


Figure 31 —West End bracket-arm hanger.

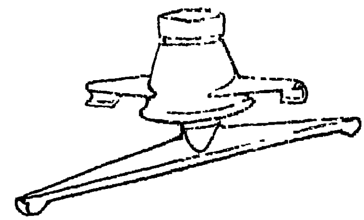


Figure 32.—West-End straight line insulator.

The bracket-arm hanger (figure 31) and the straight line insulator (figure 32) are used where the line is straight, according to whether bracket or span-wire suspension is employed. On curves with span-wire suspension the single or double pull-off insulators (figures 33, 34) are employed; the steel wires hitching on to the projecting arm to pull the line into, and

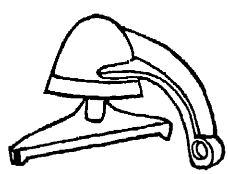


Figure 33.—Single pull-off.

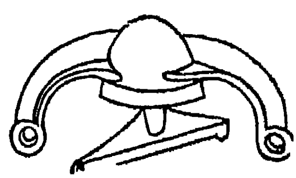


Figure 34.—Double pull-off.

retain it in, its required position. In this case the steel wire is not "alive," but is insulated from the line by the ordinary insulated hanger. The trolley wire itself can only be made to follow the curves in a succession of short chords, all supported by bearer wires radiating from the centre of the curvature. From this central point heavier bearer wires go off to the poles at the side. The second trolley wire on a double track will in the same way be supported by continuations of the wires from the first. In the case of bracket construction the use of longer chords is necessary, unless the poles are to be very close together; the actual arrangement in each case is worked out so as best to suit the conditions. Where the line passes

under a bridge or tunnel, a bridge insulator, very similar to the others, but arranged differently at the top, is bolted on to it, and a somewhat similar form is used in the car sheds.

At feeding points the insulating bolt is replaced by a hollow bolt, in which the connection is made both to the feeder above and the line below. In such cases as well as with pull-off wires the insulation is obtained by supporting the gear between "strain insulators," (see figure 35) which are also used for span wires in order to give double insulation at all points. These are also arranged to interlock in such a way that if the insulation is destroyed, the suspension still holds good by its metal parts, which may earth the line and open the circuit-breakers, but any way prevent the wire from falling. Where it is desirable to be able to adjust the strain, to take up slack or to allow more, a similar arrangement is used in combination with a turnbuckle. Specially heavy pieces are also used for holding up aërial

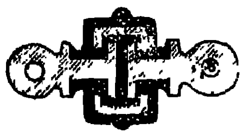


Figure 35.—"Giant" strain Insulator.

crossings and points, and for taking up the great strain at terminals.

At every half-mile the line is interrupted by a "section insulator" (figure 36), which differs from an ordinary straight line insulator in being divided up into two parts electrically

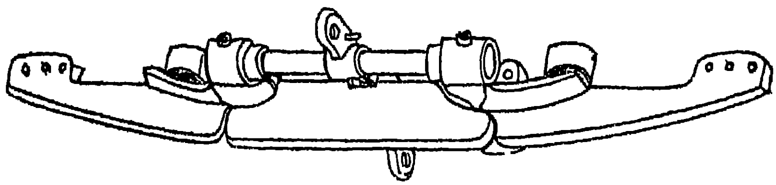


Figure 36.—Section Insulator

separate. The trolley wheel can run right over, but it breaks circuit in the middle, where the conducting car is replaced

by a short length of wood or similar non-conductor. The two parts of the section insulator are held together by insulating bolts at the top, and electrically connected to each ear is a clamp in which the isolating switch wires or feeder wires are held.

The number of all these different pieces of apparatus that are required in construction and their ordinarily accepted names are shown in the table below, on the authority of Dawson—

Table Names of Parts and Approximate quantities of Material used in one mile of line construction.

Names of pieces used	Cross Suspension		Bracket-arm Suspension		Simple Curve		Branch Curve.		Anchorage.		One, 200 ft turnout.
	Single track.	Double track.	Single track.	Double track.	Single track.	Double track	Single track.	Double track.	Single track.	Double track.	
Straight line insulator	46	92	.	..	...	...	...	..	..	...	..
Single pull off		...	..	..	3	3	3	5	...	...	
Double „	..	...	.	.	4	11	3	12	..	..	4
Bracket-arm insulator	—	..	45	90	..	..	...	..	...		..
Frog		.	.	.	..		1	2	...	.	2
Plain ears or clips	45	90	44	88	5	10	5	15	...	..	4
Strain „ „	...				2	4	1	2	..	..	...
Splicing „ „	1	2	1	2	..		..	...	...	..	.
Strain insulators	92	92	...	...	4	4	2	9	1	2	8
Insulated turn buckle „ pull off	..	...	..	...	4	4	2	2	1	2	...
Crossing		.	.	...	...	...	2	6	..	...	4
Uninsulated turn-buckle.	46	46	..	...	...	...	...	1	.	..	4
Number of poles ..	90	90	45	45	2	2	2	2	2	2	2
Suspension wire in feet	3,000	3,000	..	.	800	800	800	800	500	500	100
Trolley wire in feet .	5,280	10,560	5,280	10,560		..	.	...	...	200	200

Frogs, points and crossings are more difficult to deal with on the trolley wire than on the rails. Every possible arrangement of rails has its counterpart in the overhead equipment, and yet it is by no means infrequent to see the trolley-pole hauled down at these places and the car allowed to run past by its momentum, showing that the car conductors have not full confidence that the trolley wheel will run through properly. The arrangement adopted is to let the trolley wheel run in between guides at the crossing place, arrangements (automatic or otherwise) being made to guide it where it is intended to go. The wear on the trolley wheel is apt to be excessive at these places, and if it were run on and off the trolley wire always that also would be liable continually to break down; so at the points and crossings the web in the bronze casting takes the place of the wire, which is run up

through a hole and soldered at the top, as shown in figure 37—an arrangement similar to that of the splicing ear.

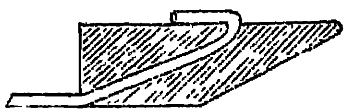


Figure 37 —Web of aerial crossing

In erecting a trolley line the ground is first marked out for the positions of all the poles, which are spaced out evenly at about 120 feet apart on the straight and as required at crossings and curves. The poles are then erected either vertically or at the proper rake to suit the strain they will be subjected to. Brackets or span wires (as the case may be) are then put up with the insulating parts of all sorts. In span-wire work the stranded steel bearer-wires themselves are insulated by strain insulators, in addition to the suspending insulators of the trolley wire. Next the trolley wire is carried along and attached temporarily to its supports. It is then fixed permanently at its terminal point, strained up and soldered to the ears all along—which are attached to their insulators either before or after according to the method of insulating adopted. The work on the line is done by means of adjustable tower wagons, of which several may be seen in Calcutta streets at present, arranged with a platform at the top on which several men can work.

Guard wires.—Where telegraph, telephone or other wires cross the trolley line, it is the general practice to put guard wires over the line to prevent the charging of any falling wire. These guard wires are sometimes themselves a cause of accidents, though they no doubt save others; one authority has aptly described them as a "necessary evil." Here in Calcutta, where we have bare overhead wires for electric light, electric traction, telegraph, and telephone, the problem of guarding is somewhat acute, and a committee was recently convened to report on the best methods of doing it. None of the alternative methods to guard wires was suggested for trial, but it was agreed that these should be made more effective, as

regards electric-light circuits, by enclosing the lines between four guard wires, interconnected by loops at intervals, as

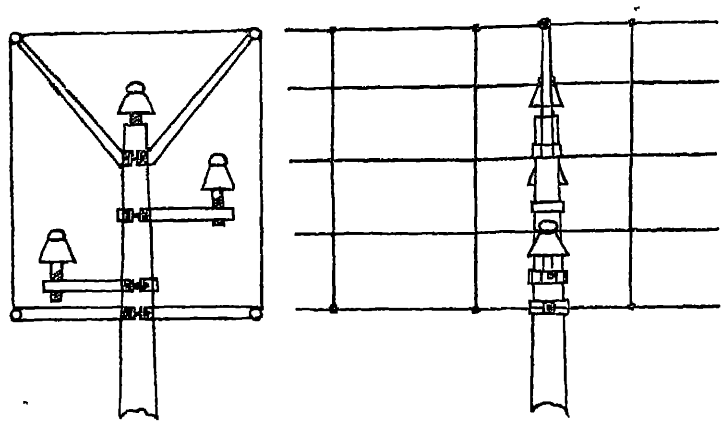


Figure 38—Guarding of bare electric supply lines, Calcutta

shown in figure 38, so as both to prevent a wire falling at right angles from whipping round, and also to catch a parallel wire. For tramway circuits this complete looping is inadmissible, as the trolley pole must be free to run along, but the telegraph or other foreign wires can sometimes be so enclosed instead, which is, in my opinion, the very best method when there are not so many as to make the framework unduly cumbersome. However, guard wires are generally run above the trolley wire and may do some good, though some experiments recently made in Madras go far to prove that the falling wire, if it breaks at some distance from the tramway lines, will, nevertheless, curl round and make contact to the guard as ordinarily erected. The subject is a very difficult one. The method of guarding which has been adopted by the Tramway Companies in England, at the instance of the Postal Telegraph Department is shown in figure 39. In Appendix IV will be found the rules on which this arrangement is based. In each case the outside guard wires are 8 inches horizontally from the live line, and the number depends on the distance between trolley wires. Experiments made in England—where wires were purposely cut down over the guards—were favourable to the method, and it has been generally adopted in Calcutta. Of course all guard wires are frequently earthed, so that if they make contact with the live line, they should invariably burn out.

Occasionally, however, they have only got red hot, where earthing has been infrequent and inefficient.

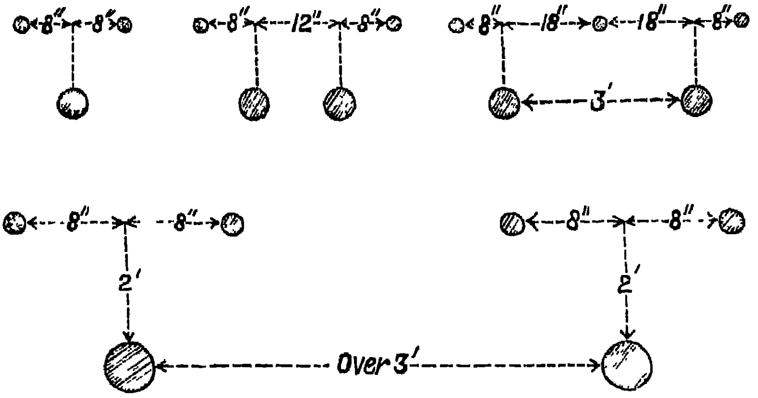


Figure 39.—British Post-office methods of guarding

Another very common way, especially on the Continent, is to run a strip of wood along the top of the trolley wire, attached by small brass clips, so as to prevent contact at the time of falling of any other wires. This is very well so far as it goes, but the falling wire will probably curl up and make contact below, or slide along to beyond the strip, and the general opinion is that the method is utterly useless. In the case of bare electric light lines I recently noticed a long bamboo threaded on a wire at the point where a telegraph line crossed it. It looked hideous, but should certainly prove effective!

The great majority of people in England are agreed that the best way of preventing foreign lines from falling over live-power lines is *to remove them!* It was with this view that the Joint Select Committee, whose report I so frequently refer to, recommended that facilities should be granted to telephone undertakers to lay their wires under ground. In many places this has been done; in others the local authorities have ignored the recommendation and refused, even though the tramway undertakers have been willing to pay the expenses involved, seeing that they are bound by rules to guard in some efficient way. It is not of course necessary to do this except where the wires cross—often a single span only need go under ground. A less expensive and also effective way is to bunch the crossing wires into a cable and suspend it over the crossing, but there are disadvantages to this course. Where single wires cross it is advantageous to support them on the same post with the power wires, as

in case of breakage at the support the wires will then fall clear. In Bengal I fear we must be content with guard wires, for there is no question that underground cables have not at present proved altogether a success, especially of such sorts as are used for telephone work. The lead covering rapidly deteriorates.

Collection of current—Siemens bow.—There are two ways in which the current can be taken off the line, namely by a trolley wheel or by a sliding bow, the latter being used very largely in Germany, but not, so far as I am aware, elsewhere. In both cases the collecting gear is pressed upwards against the wire by powerful springs, which allow the necessary latitude of vertical movement.

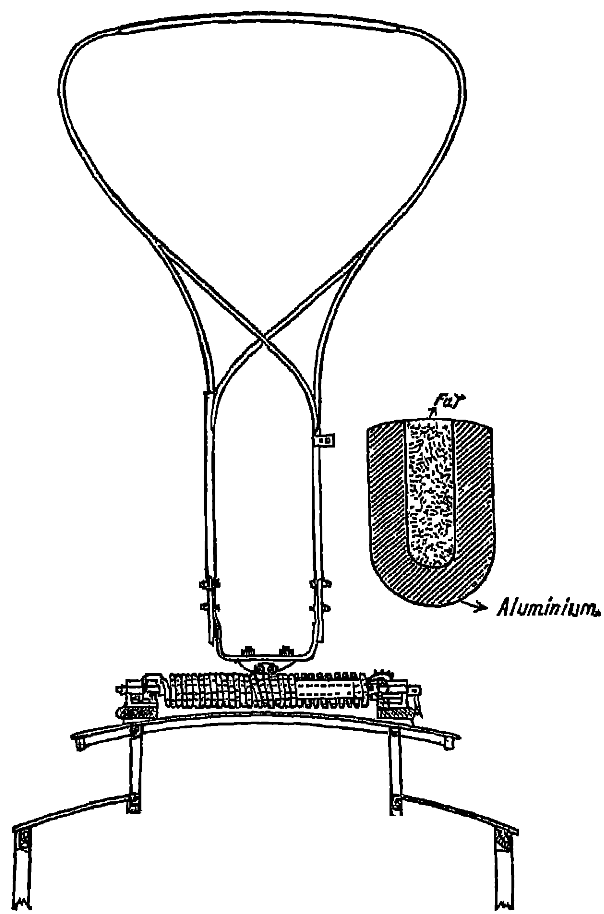


Figure 40.—Siemens collecting bow.

Figure 41.—Cross section of contact piece

The Siemens bow (shown in figure 40) is built up of a light steel tubular framework carrying on the top a slightly convex aluminium bridge of U section (figure 41), which simply rubs along the wire and so collects the current, nearly all the wear being taken up by the bow. Very considerable variation in the position of the line can be allowed, for the conducting part of the bow is some 4 feet long. It has no horizontal motion, the wire travelling about on it freely as its position changes. One would think that there would be on the whole a more intermittent contact with the bow than with a wheel, especially as the bow naturally wears down more at the points where the trolley line ordinarily lies on a straight run, but, so far as I could judge when travelling on these cars, there was very little more sparking than with a trolley. This wearing down at particular points is minimised by giving the trolley wire a somewhat zigzag course, so that it seldom keeps at one point on the bow for long. A good contact is essential always, not only to save wear, but also to prevent induction on neighbouring telephone wires at the make and break; for it is no use specifying that generators are to "produce a continuous current without appreciable pulsation" if jumps on the car convert this into an interrupted current.

For lubrication the inside of the U-shaped bridge is filled with grease, and the wear is consequently reduced to a minimum; 20,000 to 30,000 car-miles is the stated life of the bow, while the wear on the wire is almost inappreciable. One undeniable advantage of the sliding bow is that it practically *cannot* get off the line as trolley wheels not infrequently do, and it is therefore distinctly the more suitable for very high speeds. Then, again, no special arrangements are necessary at points and crossings, which enormously reduces the complication of construction at these points and greatly reduces the unsightliness, and the line at curves need not follow the track nearly so closely as is necessary with centre-running trolleys; in fact, it is better when it does not, as already pointed out. If the direction of the car changes, the bow adjusts itself and does not need to be pulled round by the conductor. Where a very steep gradient requiring a very heavy current is met with, it is sometimes arranged that a single track only runs up it, the bow collecting off both trolley wires at the same time. Having seen this system at work in Hanover and elsewhere,

I confess it seems to me superior to the other, and I do no know why it is that it is not far more widely used.

Trolley Wheels.—Trolley wheels are made of gun metal from 5 to 6 inches in diameter, grooved deeply, and weighin some $2\frac{1}{2}$ lbs each. The groove is sometimes rounded off an sometimes V-shaped, the aim in the latter case being a botto and larger contact. They are carried on the end of a ligh tubular pole, the conducting wires being carried down in side to the cars. The conductor is electrically connecte to the fork in which the spindle of the wheel runs, auxil liary brushes sometimes collecting direct off the wheel For automatic lubrication of the spindle a bushing o graphite or carboid is often used, which increases the resist ance between spindle and fork. Automatic lubrication on the lines of the punkah wheel is also used to some extent, bu probably the best way is to have each wheel oiled after the day's run. The wear on trolley wheels is considerable, an cuts right through them after a time. With old forms o wheel this often caused the wheel to actually come to piece when travelling, but ribbed wheels (figure 42) are now universally used, as the inconvenience of coming to a stand still miles from the repair shed is obviated.

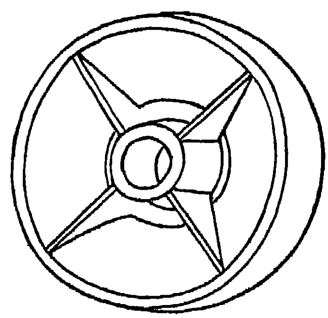


Figure 42 —West End trolley wheel.

The trolley pole that carries the wheel is in England generally fixed at the top of a pillar about 4 feet high, on or in which are fixed the springs that hold it upwards. This is because cars there carry passengers on the roof as well as inside. In countries where outside seats are not used the

pillar is not required. In any case arrangements are so made that the trolley pole can swing round for reversing the direction of travel and also to allow for the line changing its position with respect to the car. As a general rule, the trolley wires run more or less over the car, but in some places the wires have been carried on side brackets entirely clear of the track, the side running trolley pole running out almost its full length to them; even ten feet can in this way be negotiated. The trolley wheel itself, with its fork, can also swivel on the pole head so as to always meet the line true at any angle.

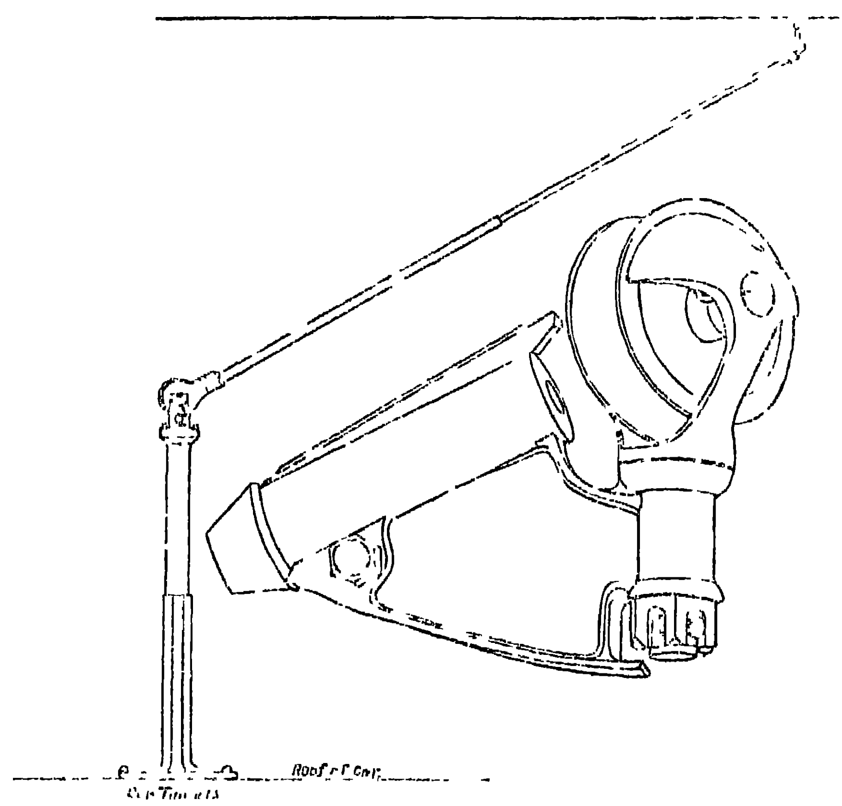


Figure 43.—Trolley pole and standard.

Figure 43(a).—Trolley wheel

The usual length of a trolley pole is 13′ 6″; outsid diameter at butt from 1½″ to 2″, and at head 1″; weight abou 27 lbs. They are very flexible indeed, capable of taking deflection of over 3 feet without permanent set, and of carry ing a strain equal to a concentrated weight of 80 to 100 lb at the end. The trolley pole by compressing its spring can come down to the horizontal position, and in th vertical direction must be capable of moving up to th highest point of the trolley wire and still retaining enoug upward pressure for good contact. Whenever double-decke cars are used, the trolley standard is electrically connecte to the wheels and frame, and thus earthed, in order t prevent all risk of shock to passengers. It is not necessaril placed in the centre of the car, as both the trolley an head can adjust themselves within wide limits.

Cars.—In order to withstand the great strain of th trolley pole, the top of these cars needs to be extremel strong as compared with those for other forms of tractio Underneath also the framework has to be designed to carr the considerable weight of the motors.

The essential requirements of a satisfactory motor truc are strength and durability without excessive weight. I must be so framed and braced at all points as to prevent getting out of square, and it must in no way depend on th car body for strength. The motor has to be spring-supporte on the truck to prevent jolting, and the whole arrangemen must be capable of easy inspection. Amongst other moder developments is the maximum traction bogie truck, whic is so arranged that with an 8-wheeled 2-motor car, the great part of the weight is distributed on the 4 wheels driven b the motors, so as to ensure the maximum tractive effor But though these cars have been, and are, very largely use there are many engineers who consider them inferior to th ordinary types. They are no doubt superior at startin but they do not lend themselves so conveniently to the appl cation of some of the best forms of brake, and there is danger of the idle wheels actually rising off the track alt gether and perhaps causing derailment.

In other respects electric cars vary as much as hor cars or railway carriages, being built open and shut, with an without top seats, with various numbers of wheels, and every stage of comfort and the reverse. The wheels ma be either steel-tyred or chilled iron, both being largely use but the former have had a much longer life in places whe both have been tried, amounting to three times as lon

American cars are the best arranged and the best looking, but travelling on them is at times rather a trial owing to the maxim obtaining there that the passenger capacity of a car depends on the number who can hold on! English cars are seldom properly lighted or warmed in cold weather; American cars, on the other hand, are brought up to our hot-weather temperature when the thermometer outside is far below zero Fahrenheit. I have stepped out of a car into an air temperature differing from it by over 100 degrees Fahrenheit! Whether the Calcutta Tramway Company will take the opposite course and fan or refrigerate their passengers is perhaps doubtful, though in Germany the railway saloons have centrifugal ceiling fans. Heating, where necessary, is now generally done by means of electric radiators fed from the line circuit, of which several are placed at different points in the car,—all in series. There are generally two independent circuits in each heater, of different resistance, so as to absorb different watts and give varying temperatures, according as whether either or both are in use. Lighting is also effected in the same way, the lamps being run in series on the full pressure, either five 100-volt or 105-volt lamps, or two 250-volt lamps, or any similar combination.

In addition to the controlling, lighting, and heating of the car, there is always a lightning arrester and choking coil and an emergency cut-off switch. The lightning arrestors may be either the same as those described in the case of the line or similar to those non-arcing arresters described in my previous lectures.

Motors.—It is now general, in fact almost universal, to use single-reduction gearing on ordinary urban street railway motors. A direct coupled motor is too heavy owing to the slow speed at which it must run, while the loss in efficiency due to double-reduction gearing, which was originally used, is too great to allow of it. Worm gearing has been used to a small extent, but it is not suitable for the rough conditions it is called on to work under. In order to reduce the noise due to the use of gearing, pinions are generally made of raw hide, which is satisfactory in every respect.

The work of traction motors is of a very different nature to that of most others; motors driving fans, or any other machine requiring an unvarying effort, are built for a certain steady horse-power which they maintain. In many machine tools the power is constantly varying by a very considerable amount, but the average power is fairly calculable. But traction motors are called upon for extraordinary

effort at starting, especially on gradients, and their average work varies also very greatly according to whether they are going uphill, downhill, or on the level. Then, again, they are subject to sudden reversal on short circuit occasionally. What is the rated horse-power of a traction motor? It is just what the makers choose to call it. A 15 H.-P. and 30 H.-P. tramway motor by different makers will perhaps be indistinguishable, the only difference being that *A* rates his motor by the continuous output obtainable with a given rise of temperature, while *B* rates his on the maximum safe output for a short time. The General Electric Company of America have adopted as their standard the torque which a motor can exert for one hour at the circumference of a 30-inch or 33-inch wheel, at the normal speed, with a rise of temperature not above 135° Fahr. This rise in temperature would be quite inadmissible in ordinary motors, and is too high even for traction motors for the plains of India, but traction motors are built virtually fire-proof. At the present time they are also completely ironclad; so that even if a motor is lit up inside, no damage would ensue outside. The recent disaster on the Liverpool overhead railway would probably—almost certainly—not have occurred if ironclad motors had been substituted for the original open ones.

Dawson states that the practical experience of many years' use has proved single reduction motors to be thoroughly reliable and efficient (80 per cent. as against 60 per cent. with double reduction), and to fairly fulfil the following essential requirements of a motor for tramways:—

(1) The motor must be as light in weight as possible, having due regard to strength and simplicity in its mechanical and electrical construction.

(2) It must be completely closed in and protected from dirt, moisture, etc.

(3) Its capacity must be ample, and it should be able to run continuously for at least two hours at its rated capacity without heating beyond whatever may be the limit fixed, say 90° to 135° Fahr. It should be capable of developing at least 50 °/ₒ more than its rated capacity, without injurious sparking or other damage, and the starting torque must be great.

(4) All the external and internal parts of the motor must be thoroughly accessible and easily taken apart, since difficulty of access means higher charges for maintenance and labour.

One of the best known and most used motors on the market is the General Electric Company's "G.E. 800" motor,

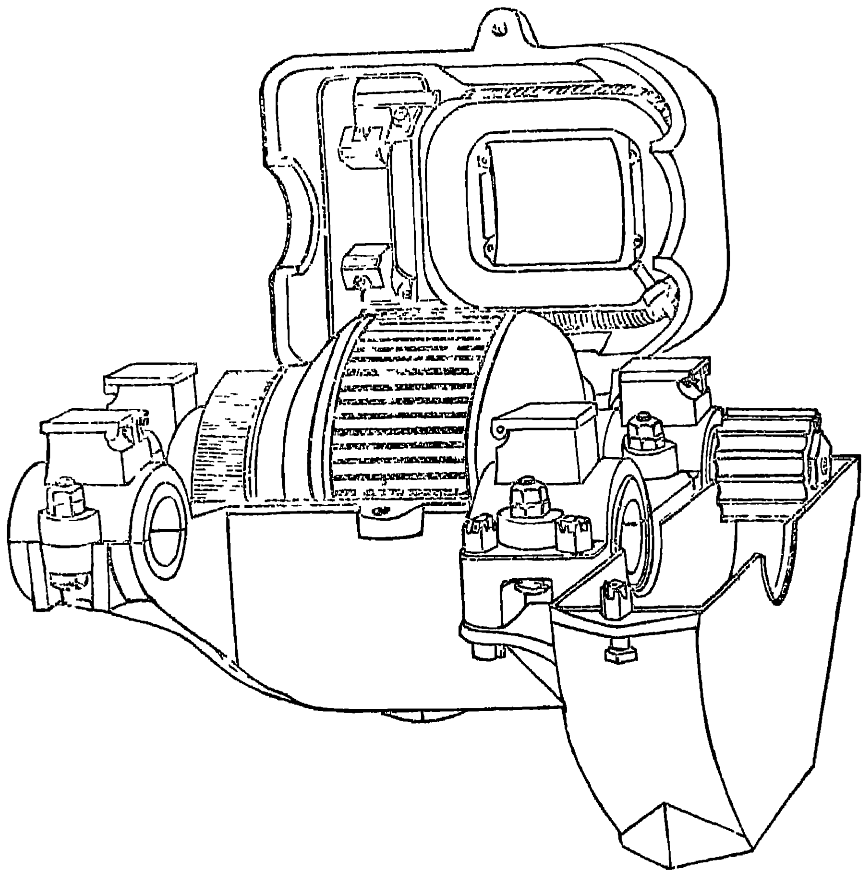


Figure 44.—Tramway motor opened

rated at 25 H.-P. It is specified under their system as capable under the usual conditions of time and temperature rise to give a drawbar pull, or horizontal effort, of 800 lbs. through a 33-inch wheel. This motor, which is single reduction, weighs 1,450 lbs.

Control.—Motors for ordinary industrial purposes, which when once started generally continue to run for long periods

under a fairly constant load, are started up in series with a resistance which is cut out gradually as the speed rises to normal. The starting resistance prevents excessive current at first, when the armature is merely a very good conductor short circuiting the full pressure; but once the speed comes up back E. M. F. plays its part and prevents a burn out. Only very small motors can be used without a starting resistance.

This method was also the first adopted in electric traction, and it is still used in certain cases. The motors —if there are more than one—are in parallel across the circuit, and the resistance is inserted in the lead common to both, so that the one rheostat controls both motors precisely alike by reducing the pressure at the terminals to a safe amount at starting or, to be more exact, by preventing it rising to normal. Of course all the $C^2 R$ watts in the rheostat are wasted, and this waste is very considerable when there are a lot of cars with close stopping places. An improvement on this method was the use of the various arrangements of the field coils in series or parallel or with parts cut out or shunted. This arrangement is known as the commutated field method, and can be used in combination with other systems.

At the present time the series parallel controller has practically ousted all others, as it not only saves a considerable amount of waste but also takes only half the ampères from the line at the start. Here the motors at first are connected in series, each getting only half the line pressure, which, however, with only a very little resistance in series, and that cut out almost at once, is sufficient to develop enormous torque at the start from rest; and this arrangement of having the motors in series, each over half the line pressure instead of in parallel at the moment of starting, introduces a great saving in energy as well as economy in what is actually used; for what was previously wasted in the large rheostats is now doing its work on the motors, and back E. M. F. has taken the place of resistance coils. In the final position the two motors are in parallel over the circuit with no resistance in, each motor working therefore on the full line pressure. The use of intermediate contacts is to give other speeds at which economical working is possible, that is to say, working with no resistance in series, and also transition points for use just when changing from series to parallel. Two other such points are obtained by shunting the field, that is, by diverting some of the main current away from the series

coils and weakening the field. This can be done in the series grouping, when running slow, in order to raise the speed somewhat, or in the parallel grouping to get full speed. In each case it of course increases the speed, since the motor must go faster in order to develop the requisite back E. M. F. under a weaker field.

Where a car has four motors they may be either permanently coupled in two pairs, each pair in parallel, and the pair treated as one motor for purposes of control, or they may be provided with connections and controlling gear for all possible combinations—4 series,—2 parallel 2 series,—4 parallel. Great variations of speed can by the last method be obtained, as in cases for instance where lines run out from a town into the country, so that there is no necessity to keep within the usual low maximum rate.

The "K" controller of the General Electric Company of America is one of the most widely-used patterns, and the various combinations (see figure 45) effected by this are as follows:—

(1) Motors in series and all resistance in circuit.
(2) Ditto and half resistance in circuit.
(3) Ditto and all resistance cut out.
(4) Ditto and shunt across field.
(5) Same as position (2).
(6) One motor cut out, the other in series with half the resistance.
(7) Same as (6).
(8) Motors in parallel with half resistance in series.
(9) Ditto with no resistance in series.
(10) Ditto with shunt across field.

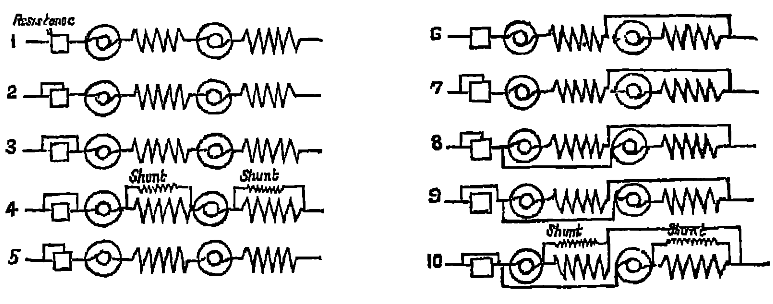


Figure 45.—Diagram of effect of controller on motor connections.

Several of these positions are merely what is known as graduating, and are only used momentarily. The economical

points are—No. 3 (dead slow), No. 4, No. 9, and No. 10 (full speed).

The cylinder plates and contacts of controllers are made of thick iron stampings; the resistance, which is separate, is of iron ribbon. There is a reversing switch on the controller, worked by a separate handle, which is interlocked, so that it can only be used when the controller is at the off position. The emergency brake is also worked off the same handle. Switches are generally provided for cutting out either motor if one should be disabled. The arc which would naturally form on breaking the circuit and at the various changes is extinguished by a magnetic blow out, as in the case of many lightning arresters.

In a series of tests made under identical conditions in the United States, it was found that on a car with rheostatic control the mean starting current was over double that on a series-parallel controlled car—73 ampères against 32; the maximum current was 120 ampères against 85, and the Board-of-Trade units consumed per car-mile, at identical speeds, 1·56 against 1·01. Now all the points count heavily on lines where there are many starts and stops. If the units used are half as high again as they ought to be the coal bills will show it beyond doubt, and if the maximum current is far higher than it need be, there will necessarily be more plant in the central station to meet that demand and larger feeders. The diagram (figure 46), which I have taken from Dawson's work, shows well the nature of the starting curves with both methods, and the great economy of the modern controller over the older rheostat.

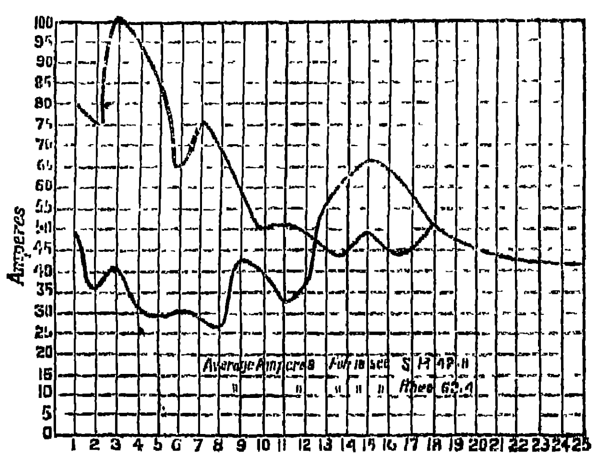


Figure 46.—Starting curves, rheostatic and series-parallel control.

Brakes.—There are many different types of brakes in use, and as a general rule two distinct kinds at least are fixed on each car. Of main varieties there are three—the wheel-brake, the track-brake, and the electrical brake; the two former including hand, mechanical, and electric brakes of considerable variety. There are two distinct uses of the brake; to retard a car on an incline so as to keep the speed within safe limits, and to stop the car either to avert an accident or to allow passengers to alight. In both cases a considerable amount of commonsense, judgment, and alertness is required on the part of the driver, and an efficient brake alone is insufficient. There is no best brake at present, though there are many good ones, and accidents through inefficient brakes or brakesmen have not been uncommon in recent years. With wheel-brakes the greatest effect is obtained just before skidding occurs, but once the wheel is held altogether the brake becomes useless and must be slackened off and applied afresh; and should this occur frequently, flats on the wheel result. This is very liable to occur when there is a light sludge of wet dust on the rails, and sanding is then necessary.

Rim brake shoes wear out rapidly, or else wear away the wheels, which is worse; and they need constant examination to keep them efficient, though they are the most used. Track brakes act direct on the rails, or in the case of very steep gradients on a special rail laid between them, and they are entirely independent of the revolution of the wheels: in fact, where track brakes are used, they somewhat interfere with the use of the other brakes, as a great deal of weight is taken off the wheels One of the great disadvantages of the hand-brake is the time taken to apply it, for a car going at 10 miles an hour travels far enough in a single second to make a lot of difference in an emergency. The action of the hand-brake is simply to press a brake shoe on the wheel or a slipper on the track, which may also be done, and much more rapidly, pneumatically or electrically.

An electric brake proper may act in one of two ways; either the action of the controller, after cutting off the line current, may connect the motor up as a generator and cause it to retard the car by dissipating the energy generated through resistance coils and the motor itself, or, in addition, there may be a magnetic frictional disc brake such as is often used on ordinary motors. In this last case the retardation is due to three separate effects, namely

that due to the motors acting as generators, the momentum of the car supplying the power to drive them, the friction of the brake disc, and the drag due to foucault currents owing to the revolution in the intense field of the brake shoe. This is all quite independent of the line current, for the brake only comes on when the line current is off, and the regulation in the braking is effected by altering the resistance in the brake circuit. On heavy grades the electric brake has one disadvantage, namely that when it has stopped the car the generators cease to give out current and the brake ceases to act, so the other brakes must be used to hold it. In addition to all other forms the emergency brake is nearly always part of the car equipment, and its effect is to short-circuit the motors (acting as generators) altogether. Its action is therefore violent, and even if the track is being sanded, there is a great chance of the wheels skidding with such a violent pull up and also of the motors being damaged.

LECTURE IV.

Power-station and General Notes.

Power-station.—It is not necessary for me to go into the question of buildings, important though it be. It is essential out here, even more than in more temperate climates, that the buildings be substantial and storm-proof, and that the power-station be roomy and lofty, well lighted, and ventilated, with proper facilities for erecting or dismantling the plant and moving it about, if necessary, for repairs. In order to reduce the great heat on the switchboard gallery, this has, in a new lighting station now being erected in Alipore, been shut off from the engine-room by a glazed partition, which, in the interest of the switchboard attendants, might with advantage be done in all cases.

The foundations for the machinery are of the utmost importance where they have to be built on little more than mud, as is the case in this district. Cases are not unknown where buildings have been begun on an insufficient foundation and have had to be finished off before the completion of the design, owing to settling taking place. With machinery this would be an even more serious matter, owing to the strains that would be set up if the bedding became uneven. Foundations for engines and generators, even when not directly coupled, are generally built in a single block, but always entirely separate from the foundations of the building.

Other buildings required are spacious car sheds, arranged with a number of parallel lines of track, each with its overhead equipment for bringing in the cars, the lines being generally arranged to slope enough to make it a simple matter to run all the cars out by gravity in case of fire. Pits run along between the tracks, from which inspection of the trucks and motors can be made and repairs effected. It follows therefore that excellent lighting is the chief essential of these sheds, and they are usually built with the same sort of roof as is general in modern factories, of  shape with the short leg glazed.

The size of the power-house depends ultimately on the number of cars in the system, and the larger the number the smaller need the allowance of power be per car. This follows because with only a very few cars if two or more happen to start simultaneously, the result is perhaps to double the output, whereas with more cars the same event

would have proportionately less effect. The two tables following are given by Dawson, the first giving the actual number of cars required under given conditions of speed and headway, and the second the power required at the power house per car with varying numbers of cars :—

Number of cars on ten miles of track.

Minutes apart or headway	Average speed in miles per hour.									
	6	7	8	9	10	12	15	20	25	30
1	100	86	75	67	60	50	40	30	24	20
2	50	44	38	33	30	25	20	15	12	10
3	33	29	25	22	20	17	13	10	8	7
4	25	22	19	14	15	13	10	8	6	5
5	20	17	15	13	12	10	8	6	5	4
6	17	14	13	11	10	8	7	5	4	3
7	14	12	11	10	9	7	6	4	3	3
8	13	11	9	8	8	6	5	4	3	3
10	10	9	8	7	6	5	4	3	2	2
15	7	6	5	4	4	3	3	2	2	1
20	5	4	4	3	3	3	2	2	1	1
30	3	3	3	2	2	2	1	1	1	1

Approximate indicated horse-power at power-station per car for various numbers of cars.

Cars.			Indicated horse-power per car.
1 to 5	...	...	... 35
5 „ 10	..	...	... 30
10 „ 15	..	...	... 25
15 „ 25	...	...	... 20
25 „ 50	...	...	... 15

There are often great difficulties about obtaining sites for generating stations in suitable positions, especially in England. There it has been recommended to alter the law and allow compulsory acquisition of land for the purpose, but this has not as yet been done. Here I understand that that procedure is already permissible, though I am bound to say that there is a wide gulf between the fact and inducing the authorities to act on it in the interests of a company as against a private owner. The technical reasons are naturally not understood, and the fact that the public ultimately have to pay in the form of higher prices or rates is not realized. The position most desirable electrically for a power-station is at the distributing centre of the lines to be run but conditions of coal and water-supply may often render this untenable. The Calcutta tramway power-station is on the extreme outside of the area supplied.

Engines.—The steam-engine is the prime mover in the great majority of tramway power-stations at present. It is not improbable that gas-engines may later on be used to some extent in places where gas is cheap, as large power-engines of this class are now practicable. I recently saw one of 1,000 I. H. P. driving the main generator for electrically-driven shops in Germany, and it left nothing to be desired. Water-power also will have its innings soon, and does already work many systems, but we must pass over this which involves also the whole question of transmission of power.

In the United States belt-driven sets have generally been employed, partly with the idea of reducing the shock to the engines by interposing the more or less elastic coupling; in Germany large, slow-speed direct-coupled units are most common; while in England the high-speed direct-coupled set is by far the most popular. All engines for traction work have to be constructed to stand a considerable amount of jar and shock without damage, and to have extremely small variation in speed under great and sudden variations in load. The amount of variation either in the speed or in the angular velocity during the single stroke is of the greatest importance, except where shunt-wound machines and batteries are used. It is the practice in most stations to use compound-wound machines working in parallel, and with these steady speed is almost as essential as in the parallel running of alternators or polyphase generators. The usual specification is to allow a variation of not more than 2 per cent. in speed when the normal load is thrown suddenly off, and in some cases $1\frac{1}{2}$ or $1\frac{1}{4}$ per cent. has even been specified and worked up to, while the variation of angular velocity should not exceed $\frac{1}{2}$ per cent. In addition to the ordinary governor, it is customary to provide slow-running engines for traction work with an emergency governor, which is adjusted to completely cut off the steam if speed increases more than about 10 per cent. This is a necessary precaution in view of the fact that the ordinary governor *may* fail to act through careless adjustment or accident, and that in such cases the result may be a burst fly-wheel. It will be remembered that this occurred in a mill about a mile from this College some few years ago with very serious results.

It was once customary to provide an almost complete duplicate plant as a reserve against breakdown; but as experience has been accumulated and design improved, this has

beenfound quite unnecessary in the majority of cases. The use of units of many different sizes is also obsolete, and the most economical unit is now decided on and used throughout, one spare set or unit being kept in reserve. Dawson gives the following table showing the plant required in various cases:—

Maximum power, I H P.	Number of engines.	Power of each engine, I. H. P.
200	2	200
400	3	200
600	3	300
1,000	3	500
1,500	4	500
2,000	4	750
5,000	6	1,000
10,000	6	2,000
20,000	6	4,000
40,000	9	5,000
60,000	11	6,000
90,000	10	10,000

The power dealt with in this table is the maximum required. Owing to the variable nature of the work, number and load of cars, etc., the average power required is about two-thirds of the maximum steady load, and it is at this average output, which may be even lower in small plants, that the plant should work most economically. It is usual to arrange therefore that the average output is obtained at the most economical cut-off, but that the engine shall be able to give one-third more power without strain or damage at the uneconomical maximum cut-off. But even the ordinary maximum steady load does not represent the utmost that may be demanded, for in case of a number of cars starting at once, or of short circuits, very severe momentary calls may be made on the plant. These are taken up by the fly-wheels, which are built extra heavy and capable of taking up these sudden loads without slowing down more than the allowable amount.

Steam and Coal consumption.—The steam consumption of engines varies within very wide limits. It is safe to assume that only unusually bad engines will exceed 40 lbs. of steam per indicated horse-power per hour for non-condensing simple

engines, 30 lbs. for condensing engines, and 22 lbs. for compound engines with first-class designs. Non-condensing 25 lbs., condensing 18 lbs., compound 16 lbs., triple expansion $13\frac{1}{2}$ lbs. are satisfactory figures. Exceptional results as low as 10 lbs. has been reached; Willans, Sulzer, and Allis triple-expansion engines, representing the best practice of England, Germany, and the United States, have consumption varying from $11\frac{1}{2}$ to $12\frac{1}{2}$ lbs. Generally speaking, the advantage of condensing is taken as about 25 per cent., and superheating also effects considerable economy.

Coal consumption per indicated horse-power per hour varies from as low (exceptionally) as $1\frac{1}{4}$ lbs. with triple-expansion engines, $1\frac{1}{2}$ lbs. with compound, 2 lbs. with simple condensing, and 3 lbs. non-condensing, but 7 lbs. and more is not unusual. When so much depends on the design of the engine, the pattern of the boiler, the quality of the coal, and the skill of the stoker or the good working of the mechanical stoker, it is not possible to lay down any hard-and-first rule.

Boilers.—Of boilers, the water-tube and Lancashire in many forms are mainly used in England, while vertical boilers find great favour in the United States. For a steady load the horizontal Lancashire boiler, consisting of a long cylinder traversed by two parallel flues, with or without cross-tubes, is both the simplest and the best. In this type the heated gases, after traversing the two flues, travel up the boiler and back again on the outside of the shell, either by diverging at the far end, travelling along the bricked flues at the side of the boiler, and then joining and returning underneath, or by joining together in the first instance at the back end and then at that point bifurcating along the sides before meeting on the way to the chimney stack. But a Lancashire boiler cannot be made to steam up in a hurry, and it is bad to attempt it, as with such a large mass of water to heat the result is great differences of temperature in different parts of the shell, unequal expansion, strains and leakage. Nor, again, is it possible to force them much above their ordinary working limits. Both these points militate against their exclusive use, though far more in lighting work, where sudden fog loads come on, than in traction.

Of water-tube boilers there is no doubt that the Babcock and Wilcox is more used than any other in England, both for lighting and traction work. In this type the furnaces

heat up a large number of water-tubes placed on a slant upwards from the back, connected together front and back, and communicating with a drum over the top of them. Obviously with such an arrangement there is an enormously rapid circulation of water and generation of steam, and there is so much less absolute rigidity in the whole structure and so much smaller a volume of water that it is quite safe and allowable to get up steam in as few minutes as it can be done and to force the boiler considerably.

Mechanical stokers are gradually ousting hand-stokers, though no one type is a standard yet. Both the reciprocating bar type or the continuous band stoker, a sort of flexible, slowly-revolving set of fire-bars, may be found side by side. Whatever boilers are used it is the almost invariable practice to use economisers, and the various other accessory requirements of the boiler-house do not differ from those in the case of any other steam-using industry, while the actual apparatus used varies just as much. Labour-saving and waste-heat saving appliances when carefully selected and carefully used are always an aid to economy.

Generators.—Whether required for electric lighting or for traction work, it is always true economy to get the very best dynamos in the market, but there are certain points in which traction requirements differ to some extent from those for lighting, and special lines have been struck out by manufacturers in each case. In considering the traction dynamo the first point to be noted is that it must be of great mechanical strength to resist shocks of all sorts. It is the universal practice to use toothed or slotted cores, the conductors being imbedded in the core, and therefore having no chance of slipping round, as would sometimes be the case if driving pegs (as used on a smooth core) were to be depended on. Drum-winding too has almost entirely superseded ring-winding; its one disadvantage was the higher insulation required on account of adjoining coils having the full difference of potential between them, and that is any way necessary in dynamos that have to always run with one pole earthed. The insulation is generally tested very severely by the application of an alternating E.M.F. of 2,500 or even 5,000 volts. In winding these armatures the almost invariable practice at present is to build up complete armature sections by winding them on a prepared former or template to the requisite number of turns, brought exactly to shape and then tied up, taped, varnished, and well baked; these

sections being then put on the core, where each one exactly fits and fills up its place. Such a method of winding is little, if at all, more expensive in first cost, while offering far greater facilities for repairs. For further mechanical protection the top of the grooves is sometimes filled in with wood strips. It is thus possible to reduce the air gaps to extremely small widths, as far in fact as can be done without risk of contact from wearing down of the bearings; but the pole pieces must then be laminated and shaped with a view to reducing sparking to a negligible amount. It is obviously impossible to shift the brushes of each machine with such a completely unsteady load, but the field windings are arranged to give an extremely strong field and practically nullify the effect of the armature reaction, rendering any shift unnecessary. Of course carbon brushes are as essential as they are on motors; their contact resistance is far higher than that of copper brushes, in fact about 10 times as great, which involves larger brush area and commutator. It is usual to allow not more than 30 ampères per square inch of contact as the maximum at full load, emergencies excepted. To conduce to sparkless running, the commutator has many segments, in order to reduce the difference of potential between adjoining ones, and the carbon brushes have to be carefully bedded down to the right curvature.

The load is so variable, and overloads are so frequent, that generators must be designed to run very cool, and the rise of temperature allowable in cold countries should be reduced where the normal temperature of the air is very high. To assist in keeping machines cool, the core is built to allow ventilation through special ducts left at intervals, and heating in the core itself by foucault and eddy currents is provided against by carefully insulating each disc and avoiding the use of through bolts, which would destroy the effect of the completeness of the lamination. Large bearing surfaces are also essential to avoid heating of the journals, and possible stoppage from that cause.

Traction generators are built on very ample lines for their rated capacity, which is generally estimated on the normal load, since they have to stand both prolonged overloading and great temporary fluctuations of load above normal. American manufacturers allow for an overload of 25 per cent. above the rating for two hours without undue heating, and for momentary overloads up to 50 per cent.

excess without shifting the brushes or injurious sparking. The usual pressure on the line is 500 volts, which is the maximum allowed by the rules, so that feeders have to be supplied at from 500 to 550, or even 600 volts.

Where batteries are used, the generators are shunt-wound, and the regulating arrangements are similar to those in lighting stations on the same system. In many English stations they are so used and they have the effect of enormously reducing the strain on the plant due to sudden overloads, converting a peaked and hilly curve into comparative smoothness. In the United States batteries are little used, and the generators are compound wound and over-compounded to give the required no-load and full-load volts. The use of these over-compounded generators is spreading rapidly in England at the present time. The employment of them in parallel is not such an entirely straightforward matter as with shunt machines; it is necessary for the machines to have approximately similar characteristics, and care has to be taken to see that the machines divide up the load properly. In addition to the ordinary connections an "equalising circuit" is necessary, *i.e.*, a low-resistance lead between the positive poles of all the machines, with equalising switches to make the connection in each case While the ordinary regulation is carried out by means of the shunt resistances, any necessary variation in the overcompounding can be effected by the use of a shunt placed across the series magnet coils, which offers an alternative path to the current.

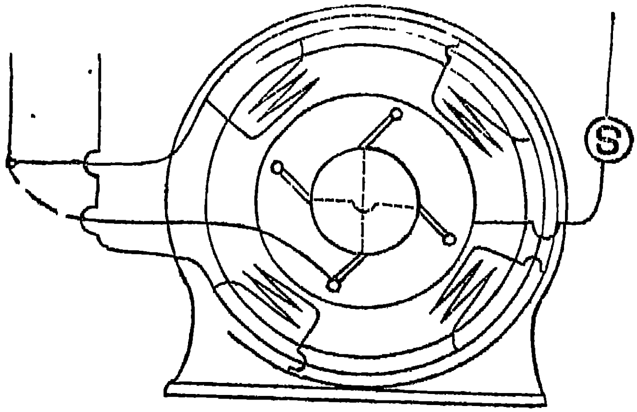


Figure 47.—Connections of 4-pole generator

Switch-boards.—The making of electric traction main switch-boards has now become to a large extent standardised, panels of various capacities being built up and the required number assembled for any particular piece of work. There are separate generator panels and feeder panels, and only in small installations are these arranged in combination. In any case a "Board of Trade panel" is provided to carry the various instruments called for by the rules. Slate or marble is used for switchboard work, freedom from flaws and metallic veins being essential. All instruments and apparatus is put in front, and all connections are made at the back. In the great majority of tramway stations I have visited, the Weston type of instruments are used; they are dead beat and have an evenly-divided scale, which is greatly in their favour.

On generator panels there will be a quick break-switch on each pole and also a magnetic circuit-breaker for excess current, placed between the main switch on the negative pole of the generator and the bus bar, that is on the pole which goes to the rails. In the usual form this consists of a switch held locked by a catch, which will be released if the current in a solenoid increases beyond certain limits. In that case the switch opens and the actual break occurs at a subsidiary switch, whose working point is in the field of a magnet powerful enough to extinguish the arc formed. The ampèremeter used for this work must be capable of showing the highest current attainable by the generator, not just its normal full load. In the case of using compound-wound generators the equalising switches are as a rule on separate pillars near the machines, and not on the generator panels. In these cases also there is a variable shunt over the series coil, capable of varying its current and regulating the over-compounding. There will be a shunt resistance also to bring the machine down to about 300 volts, and a shunt-breaking coil to take the spark and prevent the burning out of the coils. A voltmeter and a recording wattmeter are also part of the equipment, the latter being the only way of really telling what amount of energy is being used on so variable a circuit. The ordinary ampère-hour meter of central lighting stations is sufficient only when (as there) the average pressure is obtainable from the voltmeter readings, which are regular and uniform as the load rises and falls in a manner capable of almost accurate prediction.

I have already described one form of lightning arrester considerably used in traction work, but I may here mention

another form which is of great use in countries like India, where thunderstorms are frequent and violent at certain seasons. I refer to the tank arrestor, whose function is to permanently earth one pole (or in electric lighting work both poles) through fairly high resistance. Such an arrestor is only put in circuit on the approach of a storm, and during that time will cause a leakage of perhaps 20 ampères. Should a discharge occur, it goes straight to earth through the water in the tank. I had such arrestors put up in Viceregal Lodge, Simla, where I believe they have acted well. The Siemens horned arrestor, with or without a magnetic blow-out, and the Garton-Daniel are also largely used in traction work.

On the feeder panels each feeder is brought up to a circuit-breaker, as before, to open in case of excess current, as for instance a heavy short circuit on the line. Often as a precautionary measure an earthing switch is placed on each car, capable of putting the line direct to the truck and rails in case of an accident likely to endanger the public, so that the feeder circuit-breaker will open and cut off the line. It is a general rule in stations to close the circuit-breaker three times in succession, and if it still opens the attendant knows there is something seriously amiss, and takes steps to put the repair gang in motion. Fuses are only occasionally used, where the current is small, since they give more trouble in replacing. Quick break-switches control each feeder, an ampèremeter is in circuit, and often a wattmeter also, as in the case of the generator panels.

"*Board of Trade Panel*" (*figure 48*).—This is a special panel which has been designed, and is always used, to show that the conditions required by the Board of Trade rules are carried out. I shall discuss these rules, as adopted by the Government of India, presently, but for the moment will simply mention how the panel is made up. There is a recording ampèremeter reading up to 10 per cent. of the average load of the station, whose function is to measure the current returning by pipes, etc., instead of by the rail return proper. It has to be connected through switches to two independent earth plates (rule 58, Appendix I). There is also a very low reading ampèremeter which is used to measure the leakage from line to return (or from either to earth when both are insulated) after the cars have stopped running. Two scales are provided, and the instrument will read either from $\frac{1}{50}$ to 2 ampères, or from $\frac{1}{2}$ to 10 ampères (rule 62). Then

there is a recording voltmeter reading from 0 to 10 volts for taking the drop in pressure on the rail return (rule 59). There is a polarised ampèremeter to show the direction of the current at the earth plates, and arrangements are made for testing the resistance between the earth plates (rule 57).

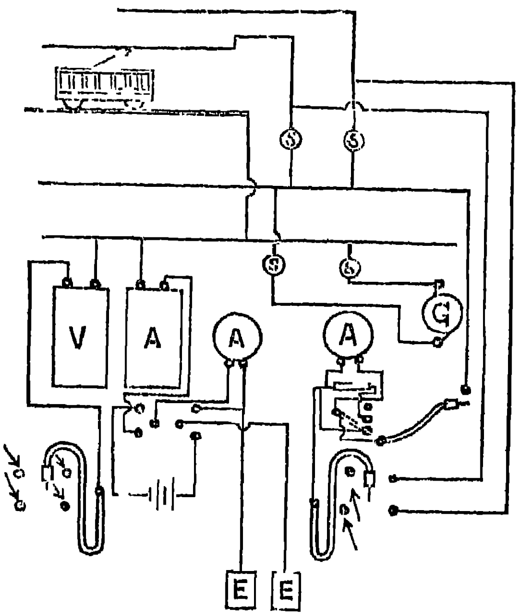


Figure 48.—Board of Trade testing panel.

Having now surveyed the whole field of electric tramways superficially, but to such an extent as has been possible in the time at my disposal, I will turn to a number of points which have so far received insufficient notice.

General notes.

Power and acceleration.—The power required to run a given car depends on several factors: the rolling weight and speed, the condition of the track, whether straight or curved, clean or dirty, the gradient, the windage, the friction of the bearings, the efficiency. On any given gradient the tractive effort required to give any constant speed varies directly as the weight of the car. As the gradient becomes steeper, so does the required tractive effort or pull increase in order to maintain any given speed. The brake horse-power, again, varies directly with the speed. When acceleration is taking place, the power required is of course proportionately greater than at a steady speed, and the effect may be expressed as though the gradient were increased. Thus an acceleration of 1-foot-per second per second requires the same effort as an additional 3·1 per cent. gradient. This rate of acceleration produces a speed of 10 miles an hour from rest in about 15 seconds, than which far more is obtainable by electric traction; in fact 25 miles an hour can be attained in 10 seconds on electric railways in practice, which is about as great as the comfort of passengers allows. Such acceleration cannot be approached by steam locomoties, which is one reason among many why electricity is so vastly superior for traffic requiring quick runs and constant stoppages.

I would call your attention to the very handy series of diagrams of tramway tractive effort and power by Mr. A. G. Hansard, published in the *Electrician* for October 11th, 1901, from which estimates can very rapidly be made under the most varying conditions by simple inspection. A small portion of the diagram is here reproduced to show its scope (see Plate II). Thus a car weighing 6 tons requires a drawbar pull of 180 lbs. on the level, and for a speed of 5¾ miles per hour requires 2·8 brake horse-power, or 5 ampères at 500 volts, assuming 80 per cent. efficiency in the car equipment. The same car on a gradient of 1 in 275 requires a drawbar pull of 260 lbs., and requires the same power at a speed of 4 miles an hour, and so on.

In any given system it in necessary to make careful calculations as to the average and maximum power required. I have already mentioned this in previous lectures, giving both some formulæ (on which probably these diagrams are based) and also rough figures as to the approximate ampères required per car at 500 volts. These rough estimates would

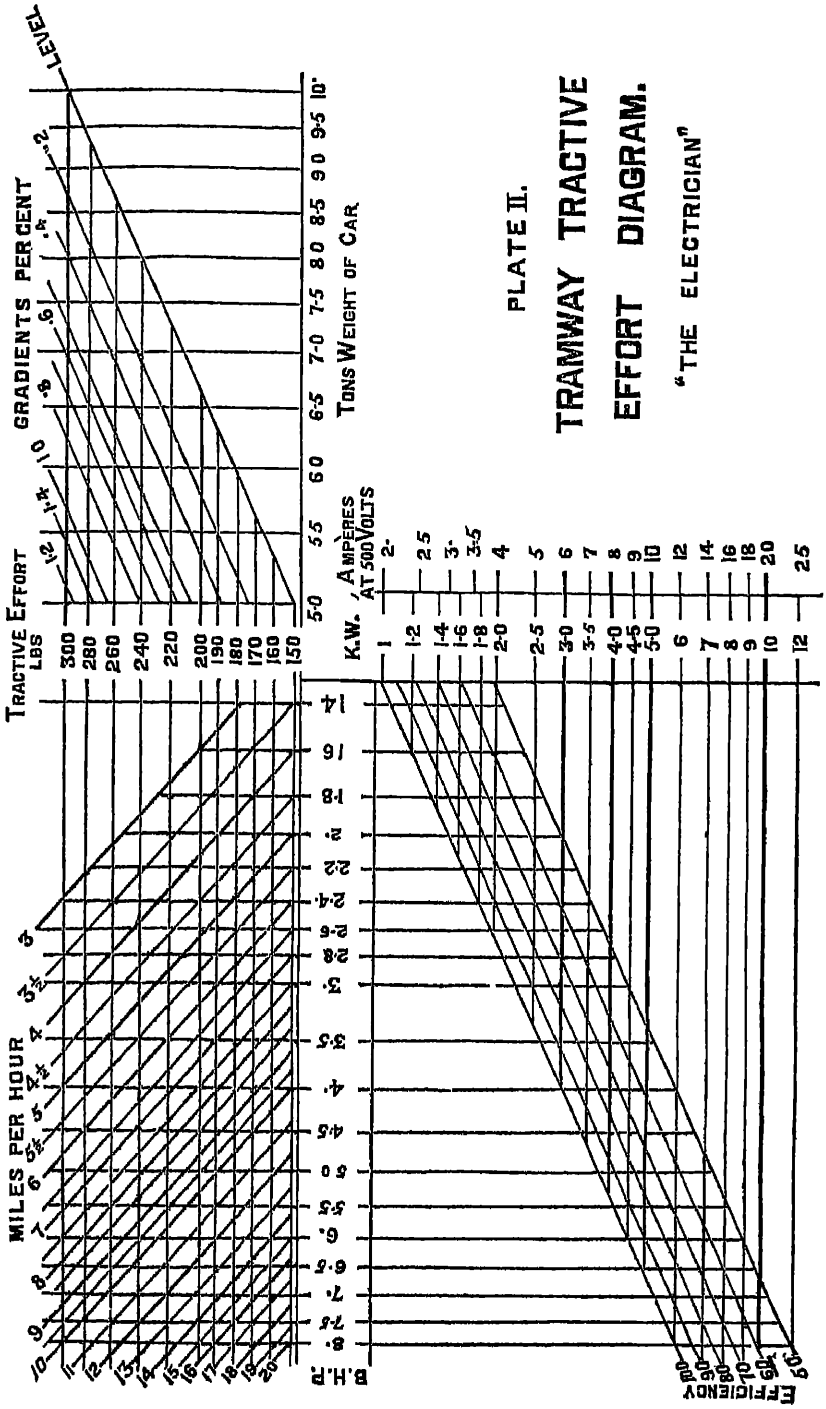


PLATE II.

TRAMWAY TRACTIVE EFFORT DIAGRAM.

"THE ELECTRICIAN"

of course only serve in the first stages of the work. It is here that these diagrams come in to save a great deal of labour; for the number of cars, speed and headway being determined, they can be plotted on a map showing the gradients, and the power required for each section can be worked out rapidly as well as the current in the feeders.

Speed.—The speed actually allowed varies greatly according to the locality, length of runs, and conditions imposed for the safety of the public. Railways are proposed both in England and Germany for speeds of 100 miles an hour and upwards, for covering the distance between towns quickly and without intermediate stops, and in the latter country the cars of an experimental line were actually shown to a number of electrical engineers, including myself, who were over there last year. For a railway dealing with local traffic and stations fairly close together, about 30 miles an hour is the economical limit; where the public have access to the lines in towns, as on a tramway, about 10 miles an hour is the highest which can safely be counted on, though in America the cars often run two or three times as fast. The quickness of a service depends on 4 factors—rapid acceleration, speed of running, rapid retardation, and duration of stops. The latter item counts for a great deal where stops are frequent, and a second or two is generally sufficient on tramways. On the Central London Electric Railway the trains often stop no more than 9 seconds, even dealing with heavy traffic and many passengers. This all tends towards an efficient and economical service.

Boosting.—The use of motor-generators or boosters in electric-traction work is twofold; they may be used in the ordinary way in series with the feeders or line, transmiting the full current and adding to the pressure, or they may be used negatively, to (so to speak) suck the current back from the rail circuit at distant points on the system, and thus reduce the fall of potential on the uninsulated part to proper limits (see figure 49).

For example, a return or negative feeder will be run from a large meeting place of many tracks, and there connected to all the rails. Naturally the return current will go back to the station largely by that feeder in preference to the higher resistance rails. But if there is a generator (motor driven) connected in the power station between the negative bus bar and the end of this feeder in such a way

as to force a heavy current back along the feeder, the current there has no option! It is equivalent to greatly reducing the resistance (or increasing the conductivity) of the return circuit and feeder.

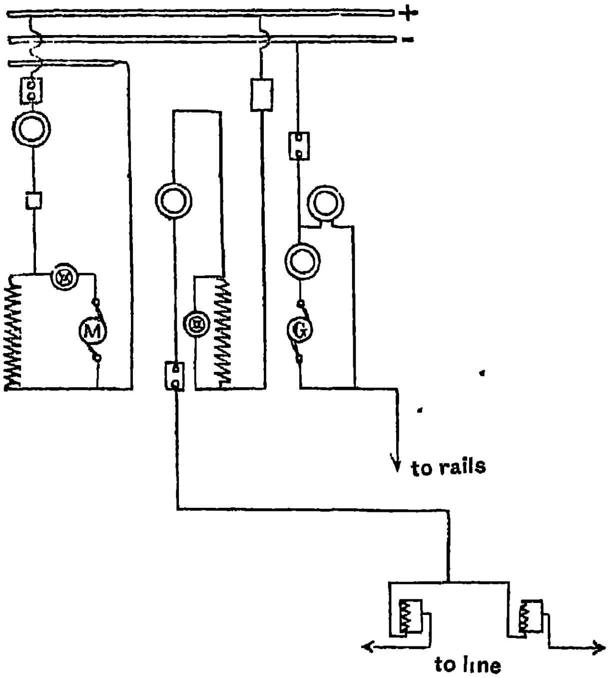


Figure 49.—Negative Booster connections

You can compare this with the boosting arrangement in use on the 3-wire lighting system in Calcutta. Owing to various causes, some of which are peculiar to the country, that system gets out of balance very considerably, rendering some regulation on the distributing network imperative. This is obtained by motor generators, which add load to the lightly-loaded side of the system while taking it up on the heavily-loaded side. In that case the shunt field of each machine is

excited from the opposite side of the system to its armature, and series winding thus rendering the arrangement automatic.

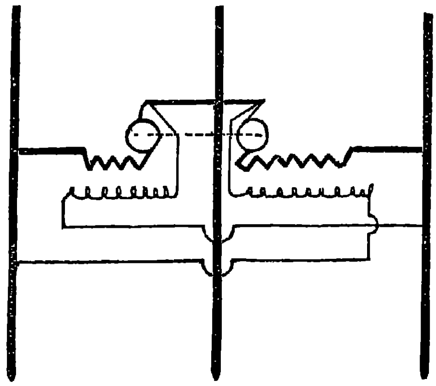


Figure 50.—Automatic Boosters on lighting system in Calcutta.

Electrolysis.—In the case of traction circuits it is with a view to preventing damage to underground metallic pipes and structures that negative boosting is employed. In dealing with the track and bonding of rails I drew attention to the rule prohibiting a greater difference of potential than 7 volts on the return, rendering large rails and good bonding necessary, and sometimes negative boosting and return-feeders also. Neglect of any precautions of this sort have caused great troubles in early days, since a small difference of potential will cause electrolysis in the presence of salts (especially chlorides) in the soil. The surface of rail which is in contact with the ground is very large indeed, and when, owing to the nature of the salts in it and the amount of moisture present, there is good conductivity, a large amount of leakage may take place with comparatively low difference of potential. When there are gas or water-pipes in the neighbourhood, there is always a danger of corroding them if proper precautions are not taken; and since electric traction had its early struggles chiefly in America, it is there that most trouble was met on this account. A drop on the return of 30 or 40 volts was once no uncommon thing there, since the rails alone and unbonded were used, and the greater part of the current actually returned through earth and the gas and water-pipes, to the detriment of these. It was only when the disastrous effects of this false economy were realized that the matter was properly investigated and the remedy applied.

In order to eliminate damage to pipes where an "earthed return" is used, it is essential that the return be negative;

it is also essential that the supplementary uninsulated return-conductor (if any) be laid close to the rails and cross-bonded to them at frequent intervals; but supplementary wires of this sort are now considered as practically useless. It is better to spend the copper on proper bonding and return-feeders. In discussing the rules presently I shall return to this point.

Of course it stands to reason that all damaged pipes are now debited to the nearest electric tramway; but as a matter of fact there is much evidence that they are not alone to blame. Many cases have been found where the pipes were damaged by chemical action of salts in the ground, unaided by electricity at all. But where an earth return is used this action will no doubt be hastened, and in some cases damage will be done indirectly by the chemicals formed, in the ground, from the action of the current on the salts present, and not by direct electrolysis of the metal.

Interference.—Another effect of the introduction of electric traction is that telephones, telegraphs, electric signalling apparatus, and magnetic instruments may be injuriously affected in their working. Of course this is not the case with the accumulator system; and with the use of a complete insulated metallic return, properly constructed, there is also no trouble. But unfortunately these systems of traction are altogether at a discount. As regards the last point, when the first electric railway started in London, the magnetic instruments at Greenwich Observatory were seriously affected; so much so that it practically became impossible to tell what fluctuations were due to terrestrial magnetism and what to the working of the line. As a consequence some rules were drawn up to minimize their interference as far as possible, though the only certain remedy is to locate the observatories far out of the way of any existing or prospective railway and in a place where none is likely to be required. This was the recommendation of a Committee that considered the point in Calcutta last year, and they suggested 20 miles as a safe distance.

In the case of telephones using the earth as a return, if the telephone lines are run parallel to the tramway to any considerable extent those lines are affected, unless at considerable distance, say 200 yards or more. The slight breaks on line and return in the collecting gear or wheels causes buzzing in the telephones owing to induction, and renders it impossible to hear properly; a short circuit will cause all the indicators in the exchange to fall and will make

working impossible. The remedy lies with both parties to a certain extent. The smoother the collection of the current and the better the construction, the less trouble there will be from induction and leakage; and by diverting the telephone lines out of parallelism or removing them to a distance, the effect can be still further reduced, so the tramway companies often arrange to do this. On the other hand, no trouble at all will be experienced where the telephones use a complete and twisted metallic circuit, as this will be equally unaffected by induction or leakage; such a system, too, is far preferable in every other way, and all modern telephone systems are so arranged. The one disadvantage, apart from cost, is the extra number of wires involved, since it is almost essential they should go overhead out here—underground mains of all sorts have so far proved a distinct failure in Calcutta at least, though we hope for better results.

In this connection I give an extract from an interesting paper written for the Calcutta section of the Institution of Electrical Engineers by Mr. Rebeiro, Electrician to the Eastern Extension Telegraph Company at Madras, who investigated the subject on behalf of the Bengal Telephone Company:—

'In May 1895, I was requested by the Agent of the Oriental 'Telephone and Electric Company to assist at the investigation that 'was being made into the subject of interference with telephonic 'communication by tramway currents. I reported to the Agent as 'follows:—

'"The trunk lines between the Central and Mount Road '"Exchanges and two other lines, all of which run parallel with the '"tramway for some distance were reported to be affected as follows:—

"'(1) When tramcars were in motion, a rasping and a humming '"sound was heard in the receivers, at times so great as to render '"conversations impracticable.

"'(2) When short-circuits occurred on the tramway lines, all the '"indicators in connection with the above mentioned lines dropped. If '"a receiver were in circuit at the time, a sharp noise was heard.'

"'In order to determine whether these effects were due to leakage, '"induction or earth disturbance, the following experiments were '"made at the Central Exchange:—

"'The lines were tested for insulation, and all except one were found '"to be exceedingly good.

"'One of the affected lines was made to form part of a metallic '"circuit, the other part being far removed.

"'This was done by means of a temporary line connecting the '"affected one with another line from the exchange passing some '"distance away. The sounds produced in receiver showed that the '"effects were apparently undiminished. The proved that that part '"of the metallic circuit which ran parallel with the tramway was '"affected by induction.

'"When a metallic circuit was formed of two of the affected lines, '"all disturbance ceased.

'"By a temporary arrangement, the two exchanges were connected '"by a line which in no part was parallel or nearly parallel with the '"tramway, the circuit being completed through 'earth.' No '"sound was audible in the receiver when cars were in motion, but '"a short-circuit on the tramway lines caused a momentary current '"sufficient to ring the bell or drop the indicator, showing that some '"effect was also due to 'earth' disturbances.

'"If by any means, the current taken by moving cars could be render- '"ed more uniform, the induction on the telephone lines would be sensib- '"ly reduced, and conversation would perhaps be possible. Failing this, '"the remed es are metallic circuits, or diversion of the telephone lines.

'"The first of these is certainly effectual, but would introduce certain '"complications, and financially affect future business of the Company.

'"Diversion of the telephone lines would probably be less expen- '"sive, but would not effectually guard against dropping of indicators '"or ringing of bells when short-circuits occur on the tramway lines. '"It is, however, as much to the interest of the Tramway Company as '"to that of the Telephone Company that these short-circuits should '"cease altogether.'"

"In November following, when the No. 2 Section, overhead "system, was completed, further experiments were carried out. The "following is a copy of my report:—

'"The section of tramway to be worked on the overhead system '"being nearly completed, it was decided to experiment, with a view '"to ascertain whether the telephone lines will be subject to disturbance '"by induction from the overhead system.

'"The lines between the Central and Mount Road Telephone '"Exchanges run parallel with the conduit section of the tramway for '"a distance of about a mile and a half, and with the overhead section '"for a distance of about five hundred yards. In order to confine the '"experiment to the overhead section, it was arranged to stop the '"running of cars on the conduit section while the test was being made.

'"A metallic circuit was formed, which included one of the '"trunk lines between the two Exchanges, the remainder of the '"circuit being outside the sphere of influence. All other lines, which '"were on the same posts as the line under test, were insulated The '"circuit was tested for insulation and conductivity. The absolute '"insulation was 33 megohms and conductor resistance 271 ohms. '"Length of circuit about 5¼ miles.

'"Two receivers were inserted in the circuit at the Mount Road '"Exchange. The sounds produced in them, when a tram car was in '"motion on the overhead section, were quite as much as, if not more '"than, those due to induction on the conduit section, although a much '"shorter length was under influence. This result shows that under '"similar conditions the interference with telephone communication would '"probably be more with the overhead than with the conduit system.

'"A regular and continuous "ticking" was audible in the '"telephones, even when no current was being taken by the car. '"This effect was also present on certain other lines. A receiver in

'"connection with another trunk line, the further end of which was '"insulated, indicated a similar effect. It at first seemed as though '"this had no connection with tramway currents, but when the generators '"at the power station were stopped, the 'ticking' ceased. The '"information available was not sufficient to enable one to arrive at '" the probable cause.

'"*Conclusion.*—Judging from the results of the experiments which '"have been carried out at Madras, it appears to me that disturbances '"to other circuits by tramway currents may be due to induction, '"or to variation of the earth's potential, or to both. It is worthy of '"note that, in most cases, one remedy would apply to both causes, '"for a parallel return through the affected area for balancing the '"induction would also place the 'earth' beyond that area."

Sub-marine cable companies, again, are liable to be seriously interfered with by both induction and leakage currents from electric tramways, Cape Town and Madras having both suffered from these causes. The use of an earth return is here a necessary factor in the case, and the action which, in the case of the Cape, was brought against the Tramway Company by the Cable Company led to a great deal of expert investigation and evidence. The first remedy tried in both cases was, I believe, the removal of the earthing point of the cable instruments to some distance away from the place, in order to put it out of reach of stray tramway earth currents.

As regards Madras, the following facts and inferences are from the same paper by Mr. Reboiro. It appears that the cables there are brought from the landing point to the Telegraph Office in a pipe, $1\frac{1}{2}$ miles long, carrying four cores of which two were spare. The tramway lines, which were most likely to cause trouble, ran parallel with the cable pipeline for about $\frac{1}{4}$ mile at a distance of about 75 yards, but 2 miles away from the landing point: at that date a conduit system was in use with an insulated line and an uninsulated conduit and rail return, and the collecting arrangements appear to have frequently caused short circuits. In such cases a kick was produced on the recorder slip; Mr. Reboiro as the result of his experiments considered that the effect was not mainly one of induction, but was rather due to the variations of the earth's potential in the surrounding area; and that a circuit having its "earth" anywhere in the affected area is disturbed in proportion to the capacity of the circuit and the distance of the earth connection from the seat of the disturbance. At the same time, the fluctuations of current in the tramway circuits undoubtedly caused momentary induction currents in the neighbouring parallel circuits. As a remedy the spare cores in the pipe line were used as

return lines, and were earthed, at the cable house, on to the sheathing of the cables, and this greatly reduced the disturbances, except in the case of big short-circuits. Two aërial lines were later on laid and used as line and return for the cable circuits, and this had the same effect.

The final remedy in the case of the Cape was to lay a new twin cable down for the first section of some ten miles to Robben Island, the second conductor being earthed at that point. In this way, whether the disturbance was due to leakage or to unintentional etheric telegraphy on Sir William Preece's system, the double circuit and distant earthing would be equally effective.

In the Emden-Fayal New York cable, which was laid only about a year ago, the shore end on the American side is provided with a double core for a distance of 10 nautical miles, one of these cores forming the line connection and the other being joined at its extremity to the inner side of the sheathing of the cable, thus providing an earth for the receiving apparatus 10 miles out at sea. This effectually prevents any disturbance which might have been caused by the presence of stray currents from electric tramways and railways in the neighbourhood of the cable end. It is a very wise precaution, and will no doubt be generally adopted on new cables in view of the rapid spread of electric traction.

Accidents and their prevention.—There are a number of ways in which accidents may and do from time to time occur on electric railways and tramways, but on the whole they are few in number, and the proportion grows less as the causes are investigated and remedies applied. A very serious one occurred in a tunnel on the Liverpool Overhead Electric Railway recently, where a motor got on fire and set light to the train and to a number of creosoted sleepers which were stored close by. The motors were here of an old type and not ironclad; otherwise it is hardly possible there could have been more than a suspension of traffic; also there was a very strong wind blowing down the tunnel, which aggravated the matter greatly, and, finally, it is obviously unwise to stack inflammable stuff, like creosoted wood, in tunnels.

A very frequent cause of accident in America has been the falling of bare overhead feeders or of the trolley wire. As these have a difference of potential of about 500 volts from earth, any one touched by them while at the same time in electrical connection with earth receives a very unpleasant

shock; in the case of animals, a far lower difference of potential will sometimes cause death. This breakage may occur from kinks being left in the wire, or from over-strain, or from the trolley pole fouling the wire or from intermittent contact with a guard wire and consequent arcing. But the almost invariable cause of a trolley wire breaking is that it has been overheated when soldered to the ear. Hard-drawn copper in such cases becomes brittle, and the jar of the trolley wheel eventually causes the rupture, which will almost always occur at the suspension, and generally at the splicing ears or section insulators where the wire has been bent about. Blow pipe soldering is avoided on account of this danger, soldering tools being used in every case.

Still more common have been accidents due to the falling of "guard wires" put up to guard against crossing telephone or telegraph wires. If these guards fall to earth, making contact with the trolley wire on the way down, they become a serious danger owing to their apparently harmless nature. Of course, precisely the same thing applies to the falling of telephone or telegraph wires, if they get into contact with the line through inefficient guarding. The cases differ somewhat however, for if a telephone wire falls across an earthed guard wire—nearly all guard wires *are* earthed now—and it also gets into contact with the line, the short bit between is instantly fused, and the rest of the wire falls harmlessly. But when the guard wire itself falls, it may not burn up even on touching the ground, as its resistance may just allow enough current for it to get red hot, and no more. As regards damage to the telephone and telegraph instruments, the use of a very fine tinfoil fuse is an almost certain preventative of damage. We are fortunately free here from one of the most frequent causes of broken wires, namely, snow, which, under certain conditions, will accumulate on the wires until they are brought up to three or four inches diameter, adding enormously to both the dead-weight and strain and to the area acted on by wind pressure. Obviously, in such cases the wires must fall, and they may drag the posts down too.

Now there are several methods of guarding against falling wires making contact with the line, and I have said something about them already. The most ordinary and least efficient is probably the use of a single plain guard wire run just over the line, for a falling wire probably whips round the guard and makes contact just the same.

If the guard is earthed, the section will then be cut off, and the falling wire burnt out, but if it is insulated—as in old systems using a single guard wire is not infrequent—matters are made distinctly worse than before. There is additional danger here too of the trolley pole fouling the guard wire if it jumps the trolley wire, and this has caused many accidents at crossings, etc. Single guard wires are now prohibited. Another way is to run a strip of insulating material—generally wood—along the top of the fine wire where the other wires cross,—a method largely adopted in Europe, but again affording no real safeguard owing to the fact that the falling wire can whip round to make contact. On the whole, there is no question that one of the best ways in the case of large numbers of crossing wires together, is to make them up in a cable for the one span and support it on a bearer wire. Apart from the enormous expense of putting them all underground, which alone is sufficient to condemn that method here if we want a cheap telephone service, it is very doubtful if a system has yet been found that will last. That is not so in England, but the conditions are utterly different.

Then again there is an excellent method which has been, to some extent, adopted in Calcutta, namely enclosing the wires in a hammock or cage of bearer wires interconnected, so that nothing can fall in or out. For protection against traction circuits, the crossing wires must be so enclosed, but in the case of bare overhead distribution it can be applied to the circuit to be protected, and this is done in Calcutta in many places. I have dealt with this more fully already in a previous lecture. (*Vide* page 51).

In addition to guarding arrangements there are also various devices for preventing damage when an accident occurs. Sectional switches, feeder circuit-breakers, and car earthing switches have already been mentioned. There are also several arrangements for cutting out of circuit a falling trolley wire at its point of suspension or earthing it to the rails at the nearest bracket or supporting point.

Another cause of accidents is the higher speed at which electric cars are generally run, and the consequently greater distance required in which to stop them, though improved brakes have largely minimised this. A great number of forms of life-guard have been invented, with the idea of picking up the obstructing person, or at any rate preventing him from being run over, but it cannot be said that most

of these guards are of much use except that—as a recent writer sarcastically remarked—they appease the coroner. Some catch the person in a net, generally damaging him in the process; others are sort of cow-catchers, which throw him violently off the track, while others, again, prevent him indeed from getting under the wheels, but use him as a track cleaner instead. We know that it is the fashion for coolies in this country to walk along the street, ignoring the footpath, ignoring the traffic, with their heads bundled up so as to make it quite certain they will hear no sound or warning until a few feet off; and even when they hear it, they will never look, but invariably run straight in front of the bicycle or trap, or whatever it may be. It has struck me that the best life-guard here, to cope with the existing custom, would be a light and very flexible bamboo guard projecting far ahead—10 feet or so—which would yield at once on catching a man in the back but would give him ample warning to get out of the way on his own legs!! Accidents due to a runaway from brakes not acting are uncommon now, the importance of the subject being fully realized; and as we have no hills in these parts, we are freed from anxiety on that score.

Government of India rules.—Following on the practice of the Board of Trade the present rules in force here under Act XIII of 1887 include a code for the regulation of electric traction in particular. In point of fact the remaining rules —the code is printed in full in Appendix I—apply so far as they are capable of application to all forms of electrical industry, and these are extra rules particularly with a view to the recommendation of the Joint Select Committee on Electric Powers (Protective Clauses) as regards leakage and electrolysis on traction circuits and to the safety of the passengers. As already mentioned a new Electricity Bill is now under consideration, and has recently been published for general information. Under this Bill these rules will later on be republished with such modifications as are necessary or desirable, but it is unlikely that there will be any very radical alterations.

Feeders for traction circuits naturally come under the same conditions as other underground cables as regards insulations and tests, except where specially provided for in the traction rules. Again, the rule that no conductor (other than pilot or volt lines) may be less than equivalent

to one-tenth inch diameter holds good; it is unnecessarily repeated in rule 76; in point of fact trolley wires are always much larger than this of necessity, even from considerations of strength alone. For the rest I leave you to study them in original while going on to discuss a few of the chief points in the special traction rules.

By *rule 55* the rails themselves, and any subsidiary conductor laid between or within three feet of them and used as part of the return, may be uninsulated, and by *rule 56* this subsidiary conductor must be electrically connected to the rails at distances apart not exceeding 100 feet. Where rails of very heavy section are used and properly bonded, it is quite unnecessary to use such a subsidiary conductor, the function of which was simply to increase the conducting area; in fact, the method has now been given up almost entirely. In the case of lines running very far out from the generating station, a regular return feeder (insulated) is often used as already noted.

By *rule 57 the earthed return must always be negative*, and the negative terminals of the generators must also be connected through current indicators to two independent earth connections, with a view to measuring the amount of current returning by earth itself and pipes of all sorts instead of by the bonded return. The keeping of the rails negative is of the utmost importance, as it ensures such damage as is done by electrolysis occurring at the rails themselves, and not on other people's pipes, as already explained; but the provision as to earthing the generators on to neighbouring pipes, as well as to the rails, has been much criticised. It is pointed out that, so long as no such connection is made, no current *can* get back to the generators from the pipes *viâ* earth, while to make the connection encourages such a flow. But, on the other hand, where there is considerable leakage from the rails to pipes, this method assists that leakage current to get back to the generators without any break in the metallic continuity, and prevents it from perhaps leaving the pipes and returning to the rails at a point further on of lower potential. There is no harm whatever done to any conductor, even a water-pipe, by the fact of its carrying a current, so long as it is not too large in proportion to the conducting area. The damage is done at the points of departure, which, in the case of a line of pipes, may possibly be at the end of every length, the earth acting as an electrolyte. However, this rule has recently

been somewhat modified in England, and in due course, no doubt, will be here.

By *rule 58* the earthed return must be so laid, bonded, and maintained that the leakage current shown does not exceed either two ampères per mile of single tramway, or 5 per cent. of the total current output of the station, and that at any point the direction of the leakage between the return and any neighbouring pipe, etc., can be reversed by by interposing *three* Leclanche cells in series when the current is flowing *from the return to the pipe* (*which it should be*) or *one* cell in the reverse case. Things obviously need looking to when the state of affairs is such that the return rails and conductors which should carry practically all the return current are being actually fed from metal pipes in the neighbourhood, which are not intended to be part of the circuit; and, as already pointed out, it is at these points where the current leaves that corrosion occurs. In order to ensure the carrying out of these conditions a recording ampère-meter is always kept in circuit.

Rule 59 provides for a *maximum drop of 7 volts* on the earthed return, this figure having been fixed by the Board of Trade as the maximum safe limit if electrolysis is to be avoided. It is by no means certain that this allowance is not too high even as a maximum, and certainly in the best undertakings the drop is nowhere near that figure; but in places where no rules are in force 30 and 40 volts' drop have been not unknown. The result of excessive drop—and proportionately even of the allowable drop—is to induce a certain amount of leakage into the earth, and into the best conducting part of earth, *i.e.*, the lines of pipes in the neighbourhood, or, on occasion, the lead sheathing of the neighbouring electric light or traction feeders. It is only fair the latter should suffer! In order to comply with this rule a pilot line is brought in from the extremity of each return circuit to the generating station, where a recording voltmeter is fixed. About 1 or 2 volts will be registered in the best constructed systems as a rule.

Rule 61 insists on the dividing up of the line into sections with an emergency switch between each for disconnection in case of fire or accident.

Rule 62 limits the allowable leakage of the line to one-hundredth of an ampère per mile of tramway, and provides for the actual stoppage of the system if it exceeds half an ampère per mile. This rule does not apply, however, to a double-insulated conductor system in a conduit, where such

high insulation resistance is a matter of great difficulty, and the leakage generally will damage only the two conductors in the conduit. The leakage must be ascertained daily before and after running hours.

Rule 66 insists on good contact both at the collector and wheels, since a bad or intermittent contact causes variations in the current which lead to interference with telegraph and telephone circuits. This is a form of wireless telegraphy which is quite undesirable, and in the case of telephone users it is exasperating to a degree.

Rule 68 insists on the provision of means of starting cars gradually, so as to avoid great and sudden jumps in the current and the consequent jumps in neighbouring circuits. The wording of this rule is somewhat old-fashioned, as it contemplates the rheostatic method of control which has fallen into desuetude.

Rule 70 lays down the tests which undertakers must take in order to comply with the previous rules—daily records, monthly and quarterly records, and occasional records.

Rule 71 forbids the exposure of any live conductors on any part of the circuit, except the rails.

Rule 73 limits the trolley circuit to low pressure, *i.e.*, 500 volts; *rule 74* lays down the minimum height of the line at 17 feet, and *rule 75* excludes tramway-feeders from the operation of rule 24 (1) when they are on the same poles as the trolley wire. Obviously it is useless to run them at 30 feet over crossings when the trolley wire cannot be so raised. Now, with regard to these three rules, many people are still horrified at the extent to which aërial lines are used for electric traction all the world over, and still more so at the way the use of these lines for ordinary distribution is permitted in Calcutta. It is true there have, in the past and in other countries, been many serious accidents from falling wires, but it is chiefly a matter of good construction. As work is done at the present time, it is a very much more difficult thing for wires to fall than used to be the case; strong poles, large insulators, large-sized wires, good staying, careful guarding—all these help to perfect the system.

Rule 77 limits the power carried by any line to 300 kilowatts, beyond which a duplicate must be run.

Rules 78 and 79 insist on the earthing of the trolley standard, and the high insulation of its flexible connecting cables.

Rule 80 calls for an emergency cut-off switch in addition to the controller, in case the latter fails to act.

LECTURE V.

Descriptions of some existing examples of electric traction.

THE CALCUTTA TRAMWAYS.

You will naturally expect some description of the system of electric traction now being introduced in Calcutta, which will serve as a practical example of much that I have told you here. The system is worked by the Calcutta Tramways Company, Limited, and conversion from horse traction is rapidly drawing to a close. The line across the Maidan from Esplanade to Kidderpore is leased to them by Government, while the remainder of the lines are controlled by the Corporation of Calcutta. There are some 38½ miles of track being electrically equipped, of which practically the whole is double track (19 miles). The power-station is at Nonapooker, off Lower Circular Road and Elliott Road, the site consisting originally largely of tank. The reconstruction is being carried out by Messrs. Dick, Kerr & Co. as Agents for the English Electric Manufacturing Company of Preston, whose magnificent works I recently went over.

Boiler-house.—The boiler-house contains 6 Galloway boilers and a Green's economiser of 480 tubes. Near is a large *pukha* tank for condensing water, and by this a cooling tower for the same. I think I have not previously mentioned these cooling towers; the water is forced up and allowed to fall down the inside of the iron structure, the fall being constantly broken so as both to give a long path and in order to break up the flow into drops. At the base are two powerful motor-driven centrifugal fans, forcing a current of air up the shaft. The rapid evaporation thus set up carries off a small proportion of the water and cools the remainder down thoroughly.

Engine-room.—The engine-room main equipment consists of three 500 kilowatt combined sets and a smaller auxilliary 150 kilowatt set (550 volts, 280 ampères). The large engines are by Yates and Thom, horizontal, cross-compound condensing; cylinders 21 inches and 40 inches, 3 feet 6 inches stroke, 90 revolutions a minute, steam pressure at stop-valves 120 lbs. The flywheels are 16 feet 6 inches diameter built up in sections and weighing 29 tons. No auxilliary engine is required to start them up, as is often the case with larger sets, but steam can be let direct into the low-pressure cylinder for the purpose.

The generators are continuous-current multipolar machines by the English Electric Manufacturing Company, compound wound, with inwardly projecting poles. The magnet yoke is of cast-iron, with laminated pole pieces cast in, and is in halves. In order to equalize the potential, if there should be small differences in the magnetic flow between different poles, heavy equalizing cables are run between brush and brush all round, the positive and negative cables being carried side by side in a channel-iron ring. Provision is made to put a shunt across the terminals of the series field winding, if required, in order to regulate the compounding to suit the running conditions. The equalizing switches for coupling up the positive sides of all the running machines are placed close to the generators, as it is essential that the connection should be of very low resistance, which means much copper.

Switchboard.—The switchboard is on a raised gallery at one end of the building. Starting at one end of it, the first panel controls the lighting arrangements; then comes a panel for each generator, with voltmeter and ampèremeter (Weston shunted type), main quick-break chopper switch, and automatic excess current circuit-breaker; these are arranged with a carbon break to take the arc. Then comes a similar panel for the whole output of the station, with an ampèremeter reading up to 5,000. These instruments are of the shunted type, and while calibrated in ampères are actually reading the difference of potential over a standard resistance through which the current passes. Beyond this, again, are the feeder panels, one for each positive or line-feeder. Each can be cut off by a switch as well as by its circuit-breaker, and each has its own ampèremeter and lightning arrester.

Feeders.—We can leave the rest of the switchboard at this point for the present and consider the feeders themselves. The trolley lines are by rule divided into half-mile sections, so that sub-feeders must be run along side these throughout. These are of ·19 square inch cross-section and laid down close to the track. These sub-feeders are fed by main feeders at the following points (see Plate I):—

Intersection of roads.	Size of cable. Sq. in.
Junction of Circular Road and Kidderpore Bridge Road ...	·6
" " " " and Chowringhee Road ...	·6
" " Hastings Street and Strand Road	·6215
" " Olive Street and Dalhousie Square	·6215
" " Bow Bazar Street and Chitpur Road ...	·47
" " Bow Bazar Street and College Street ...	·416
" " Chowringhee and Esplanade	·416

All these feeders are of the British Insulated Wire Company's make, and are lead-covered and laid in metal troughs on the solid system. They have been tested at the makers' works for 15 minutes at 2,500 volts.

The overhead equipment does not differ in any important way from the general methods I have described. The trolley wire is of 3/0 S. W. G. hard-drawn copper. It is partly suspended from span wires, partly from long single brackets, and partly from double brackets. Double insulation is employed throughout; that is to say, in the case of span wires there is a strain insulator in the suspension wire as well as the insulating hanger; and in the case of bracket suspension the clip above the insulated hanger is not fixed direct on the bracket arm, but has a liner of wood interposed. Of course this wood is not of any great value except in the dryest weather.

The main feeders terminate in cast-iron street pillars, with switches for disconnection, and from these the sub-feeders are taken off. The connections to the trolley wire are made at the half-mile sections, the sectional insulators having two feeder connections on them. Pole switches are provided at these points and also lightning arresters.

Return feeders.—Let us now turn to the return circuit. I will leave particulars of the track for the moment to deal with the electrical features first. The bonded rails are used for the return current, so far as the genoral system of lines is concerned, but the system is considerably removed from the power-station, which is very badly placed indeed. A single line of track has recently been run into the station from the Wellesley Street line for the purposes of the car shed, but otherwise no lines run anywhere near. Consequently the track obviously cannot convey the current back to the switchboard; and for reasons already fully explained, it cannot be allowed to find its way back through the earth and the pipes, even were it economical to permit it to do so. Return feeders are therefore a necessity, and three are laid as follows (see Plate I):—

Intersection of roads.	Size of cable.
	Sq. in.
Junction of Circular Road and Kidderpore Bridge Road	·6
,, ,, ,, ,, and Chowringhee	·6
,, Chowringhee and Esplanade	·7942

Negative boosters.—Each of these feeders is connected at the power-station with a negative booster, the action of

I have already explained in a previous lecture. They to speak, suction pumps, creating an electrical in the return feeders, aiding the circulation and ting leakage. The first of these feeders looks after lderpore line, and the booster output is 300 ampères volts. The second assists the Bhowanipur line—a extension to Tollygunge may perhaps be in con- ion also—and its booster gives 300 ampères at 60 volts. rd and largest return feeder is connected to the rails important junction of the tracks from Chowringhee, ade, Bentinck Street, and Dhurramtollah. All the rth of that point—the Strand Road, Chitpur Road, rnwallis Street, are interconnected at the far end, so re are many alternative paths for the return and the ce is virtually *nil*. The Esplanade booster gives 800 s at 120 volts.

h of the negative boosters consists of two machines on a single bed plate. The motor is shunt wound n off the station bus bars. An ingenious form of switch is used to excite and then gradually cut out stance. All the chopper switches are side by side, ar runs along them with a groove cut in it for each but these grooves are so arranged that the switches oe put on in the wrong order. The field cannot be until the armature is cut out; the armature cannot be l in until the field is on, and the starting resistance r be cut out coil by coil in the right order. It is a le thing that people in charge of motors will (if they ift the starting switch across all its contacts in a . With an eighth horse-power motor this does not n the least, as the current can generally be safely even if the armature is prevented from revolving, but ge motors it is a serious matter for the windings, and ses a considerable jump in the pressure on lighting

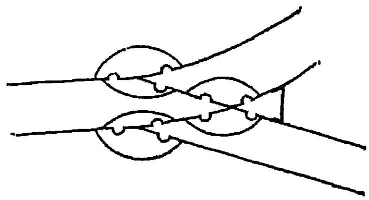
the generator side of these boosters is separately excit- the particular arrangement used was devised by ıltz, who is Engineer-in-charge here for Dick, Kerr The field is normally excited by the current in the or the particular section concerned, so that as the ises the field strength is automatically increased. be necessary, however, there is also a fine wire field which can be excited at 550 volts off the bus bars. s a special panel on the main switchboard for each

booster, the motor switches being fixed close to their machines, however.

Track.—Let us turn to the track next. The rails are of the grooved girder type, weighing 101 lbs. per yard. As nearly all the track is double, there are generally four rails to carry the return current; and as they are cross-bonded and interconnected, it will be seen that there can be very little drop in pressure. The calculated resistance of the steel rails themselves, four in parallel, and omitting joints—calculated, that is, as for a solid length—is ·0015 ohms per 1,000 feet. The resistance of the bonds at joints, omitting the rail, was estimated at 001 ohms per 1,000 feet of double track, and has turned out somewhat less. When it is considered that the tracks are considerably interlaced by crossing streets, it will be seen that the return current has the choice of various paths, all of extremely low resistance, by which to get back to the return-feeder junctions.

The track is laid on 6 inches of cement concrete, on which the broad base of the rail obtains a most substantial footing. Steel tie bars are used, of rectangular section, which are passed through a corresponding hole in the web of one rail and then given a half turn, so as to lock them by the transverse grooves in the ties. At the other end the ties have double nuts and washers, so that the rails can be adjusted to gauge and held there. For this purpose a template is used, having two projections similar to the wheel flanges, which just fit the grooves and are rigidly held to gauge on a bar. At curves a certain amount of super-elevation of the outer rail is arranged for wherever the roadway allows it, and both gauge and grooves are widened a trifle. The curves themselves are circular. On the Kidderpore line over the maidan the track is double except at road crossings. At some of these there are spring controlled automatic points, which I have already described, while at others the two tracks are carried parallel and so close together as to virtually form one large composite rail with two grooves. The reason of this is that only one car can be on the crossing at once, and the consequent danger to the ordinary traffic of having two cars running in opposite directions is avoided. Neptune bonds have been used throughout; they are only slightly different from the Chicago Crown bonds already described, and are expanded in the same way, the bond turning itself over at the outer rim under the pressure of the pin that is

driven in. At all points and special cast pieces the ordinary bonds are supplemented by long flexible bonds, which run from rail to rail and leave out the cast piece, and



Figures 51.—Bonds at points.

the two branching rails are also cross-bonded.

Rolling stock.—There will be about 100 motor cars altogether, and the old horse cars will be used as trailers. It is contemplated to use the new cars as first class at a somewhat higher fare, in order to induce more of the travelling public to use the trams. The seating capacity of the new cars is 27, and they are single-decked. American "Brill" trucks are used; the wheel base being 6 feet and the spring base 14 feet 6 inches. The trolley pole is arranged with a swivelling head, so as to run either on a wire right over the track or side suspended—the latter construction being adopted in some places. Each car has two "Short" motors rated at 25 H.-P. with single-reduction gearing and series-parallel control. The Stirling hand-brake is fitted, working on the wheel rims by differential chain gearing. In addition there is also an emergency electric (short-circuiting) brake. The lighting of the cars is done by two 3-light fittings, and these with the headlights and platform-lights make up two series of 5 each, which are across the 500 volts. I may remark here that the cars are not double ended; that is to say, they always run in the same direction, so there is a controller only at the front. At the termini there are loops, or in two cases triangles, by means of which the cars take the correct direction for the return journey. These termini are at Kidderpore Depôt, High Court, Nimtollah, Shambazar Depôt, Esplanade, Sealdah, and the power-station at Nonapooker. (See Plate II.)

Board of Trade tests.—With the exception of the last three, these loops are also "test points" from which pilot lines run back to the station for the Board of Trade test panel, to show the drop of potential on the return. Recording voltmeters, reading from zero to 10 volts, are fixed on the special test panel. There are also a recording ampèremeter, etc.

(as previously described), for the various other tests required.

Guarding.—The method of guarding against foreign wires falling on the trolley lines is that recommended by a Committee appointed in 1903 to consider the question, the report of this Committee being printed as Appendix III. The method is based on that of the British Post Office, as laid down in the rules in Appendix IV. Guard wires are carried at each side of a single trolley wire (or two close together) overlapping by some eight inches and about 2 feet above the trolley wire. This covers most ordinary cases, and various arrangements of hooks assist in the case of parallel wires, while special cases are left to be dealt with on their merits. My own view is that the telegraph and telephone wires should certainly be themselves so guarded that they cannot fall by netting or interlaced guard wires close underneath them.

Lightning.—The arresters used in the station and on the line and cars are of the Garton-Daniel type, which I have not previously described.

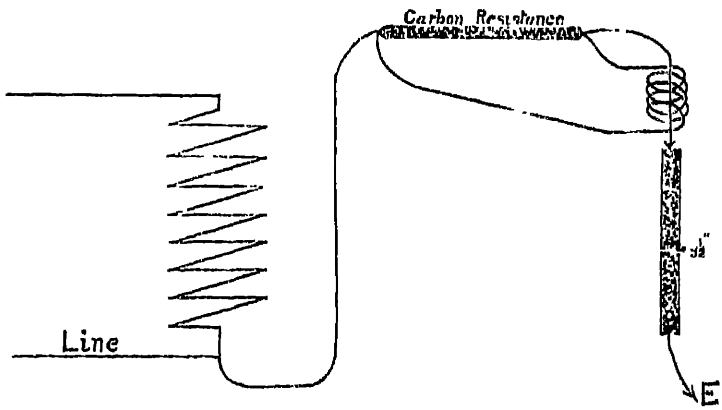


Figure 52.—Garton-Daniel lightning arrester.

The connections are shown diagrammatically in figure 52. The line to be protected comes to a kicking coil, and from the terminal is taken off the arrester connection. A spark gap is provided by two arc lamp carbons about $\frac{1}{32}$ inch apart, of which the lower is connected to earth. Resting on the top of the upper carbon is a conducting rod enclosed in a fire-proof insulating tube, surrounded by a magnetising coil, connected across the terminals of a carbon resistance which can pull up the rod. When a discharge occurs it cannot negotiate the kicking coil, so it passes through the carbon resistance, and over the spark gap to earth. The line current follows it causing a difference of potential between

the ends of the carbon resistance, the coil is magnetised, the rod drawn up, and the arc broken in the magnetic field.

BERLIN.

During 1901 a number of members of the Institution of Electrical Engineers paid a visit to Germany at the instance of the corresponding Society there, and I was among the number who availed themselves of this opportunity of seeing what other nations are doing. Naturally Berlin was the most important place we visited, and a few notes on what has been and is being done there will be of interest. There is a notable difference between Berlin and London as regards electricity supply, namely, that whereas the latter has a great number of separate central lighting- and power-stations, owned by many companies and local authorities, the former is chiefly served by one great company, the Berliner Elektricitäts Werke. The whole of this great system, with six immense generating stations and a number of sub-stations has been equipped by a single company, the Allgemeine Electricitäts Gesellschaft. It represents at present a total engine-power of some 150,000 H-P., supplies some half-million incandescent lamps, 16,000 arc lamps, 8,000 motors, and the whole tramway system. The new electric railway which I have already mentioned is, however, independent.

Power-station.—I take one particular station—that at Oberspree—as an example; this is some miles away from the city and current is generated three phase at 6,000 volts and 50 cycles. There are three combined sets, each consisting of a 6,000 volt 3,000 kilowatt, slow speed 3 phase generator, direct-coupled to a Görlitz horizontal slow-speed engine running at 83 revolutions per minute; also two 1,000-kilowatt horizontal combined sets and two 2,000 H-P. vertical sets. The large sets are being used for extensions, which are rapidly proceeding, and no less than 12 of them will shortly be running. The engines are of the horizontal triple-expansion type, having four cylinders placed two in tandem, and driving two cranks with the generator placed between. The low-pressure cylinders are nearest the crankshaft, with the high-pressure cylinder behind one and the intermediate cylinder behind the other. The high-pressure cylinder is 2 feet 9 inches in diameter, the intermediate 4 feet 2 inches, and the low-pressure cylinders each 4 feet. 10 inches. The stroke is 4 feet 11 inches. Each engine is capable of developing 4,000 B. H. P. when running at 83 revolutions per minute, condensing and supplied with superheated steam at

a temperature of 300° C. and a pressure of 170lbs. on the square inch at the stop-valve. The following table gives the outputs of the engines at different cut offs:—

Steam admission to high-pressure cylinder per cent. ...	11	18	25	35	50
Indicated horse-power ...	1,840	2,550	3,080	3,720	4,400
Brake horse-power	1,570	2,220	2,710	3,310	4,000

The condensers are placed below the floor level, each low-pressure cylinder having its own air-pump and condenser. The guaranteed steam consumption within the limits of 2,000 I H.P. to 3,500 I. H. P. does not exceed 9·4 lbs. per indicated horse-power per hour.

The generators rank amongst the largest low-speed machines yet built, the output of each being 3,000 kw. with inductive load, having a power factor equal to 0·9. The stator or stationary armature has a diameter of over 28 feet and weighs 80 tons. The core is built up of soft annealed charcoal iron segments of high permeability, which are insulated from one another, and is provided with ventilating holes. It is carried in a massive iron casting, which is supported on the foundations by four feet, the lower half being also provided with adjusting screws to enable the stator to be exactly centred with the rotor. The three-phase windings are star connected, and consist of massive copper bars insulated by micanite troughs, and carried in slots sunk in the inner circumference of the core. The end connections are made by winged connectors separated by air spaces to ensure perfect insulation. The current per phase is 290 ampères. The revolving field, or rotor, is 24 feet 4 inches in diameter and weighs 70 tons. It consists of a massive flywheel, with a ring of soft annealed iron built up chain fashion round its periphery and notched at intervals to receive the pole-pieces, of which there are 72, which are held securely in position by double wedges. At full load the excitation amounts to 31 kw., or 1 per cent. of the total output of the machine.

Sub-stations and Distribution.—Now the power from this immense station is used, as I have said, for every purpose. It supplies a large factory close by, where the cables of the Company (the "A E.G."), are manufactured, the high pressure being converted down to 1,000-volt, 500-volt, and 200-volt 3-phase currents by transformers, and to continuous current at 200 volts by rotary convertors. It supplies also the lighting and power and tramways for a considerable part of the city from sub-stations. In these the 6,000 volts is

transformed down to comparatively innocuous pressure, and then is either distributed for lighting purposes at 3 phase or put through multipolar rotary converters to give direct current. The 440-volt 3-wire system is used for lighting, while the tramway line pressure is 500 volts (continuous current) involving 550 volts at the transforming stations.

At the Moabit sub-station which we visited, the rotary converters were regulated by means of an alternating current booster on the 3-phase side; that is to say, a second machine fixed on the same shaft whose armature coils were in series with the others. By altering the field of the booster its E.M.F. can be varied, and thus the E.M.F. of the whole set—which may be either used for lighting, traction, or battery charging.

Snaefell Tramway.

This is not a modern line by any means, but I mention it as showing what can be done by electric traction in the way of grades. The line runs from Laxey, in the Isle of Man, up to the top of the Snaefell Mountain, a rise of some two thousand feet in about 4 miles; it is entirely a tourists' line, built for people too indolent to walk up, and there is only one intermediate stopping place. The gauge is 3 feet 6 inches and Tee rails are used for the track, weighing 56 lbs. to the yard. The ruling gradient is about 1 in 12, and it is actually 1 in 10 over a short length, but the cars run up by adhesion alone. The overhead system is used, with poles placed between the two tracks and double brackets. The trolley wire is 1/0 S. W. G. copper, and is fed by 37/14 feeders laid on the Callendar solid system from the power-house, which is half-way up the line. The rails are alone used for the return current, and I may point out that this is a case where excessive drop of pressure is of absolutely no importance to anybody but the Company themselves. Of course it means more coal, and in point of fact the coal all has to be shipped over from Wales, so it would be bad economy to neglect the return circuit; but as there are no outside telegraph or telephone lines or gas or water-pipes in the immediate vicinity of the line or power-house, there is nothing that could be damaged except the Company's own rails and feeder troughing. The cars have a seating capacity of 48 (all inside), and are mounted on two 4-wheel trucks, the whole motor car weighing $14\frac{1}{2}$ tons. The maximum speed is ten miles an hour, but it averages far less. There are four 25 B. H. P. 500-volt motors, one on each axle, controlled on the series-parallel system. Owing

to the extremely severe gradient and the certainty of a catastrophe in case a car should run away, the brakes are unusually multiplied. In addition to hand, emergency, and electric brakes, there is a gripper brake acting on a double-headed 65-lb. rail laid between the track rails, which is kept on during the whole down journey. The slippers have to be renewed after a very few journeys, as the wear on them is extreme. The power-station has no particular feature of interest; there are four Lancashire boilers totalling 840 horse-power, five 2-pole generators, totalling 300 kilowatts, belt driven by horizontal compound engines. When I visited this line I was informed that they had at one time used shunt motors on the trucks experimentally in order to be able to use them as generators when descending, and to feed the line; this would reduce the load at the power-station, just as cable cars do on similar gradients, or the counter-balance trams often used for short and very steep lifts The arrangement however proved unsatisfactory, as the drivers could not get into the way of regulating properly and it was considered unsafe.

Surface-contact tramway at Wolverhampton.

Quite recently a short length of tramway route was started at Wolverhampton on the Lorain surface-contact system, after some previous trials had been made with a mechanically operated surface-contact system, which has not so far proved a success. About one mile of double track is so far equipped, and has been approved by the Board of Trade, for a period of one year, and another 12 miles are to be done presently.

Operating devices.—The system is an electro-magnetic one, the contacts being operated by magnets on the car. Each box is self-contained and independent, and it is an essential to a contact being alive that the electro-magnet on the car shall be over it. A failure of the system is therefore incapable, so far as one can foretell, of leaving a contact alive after the car has left it, though nothing but continuous working can prove this conclusively. The collector under the car is just long enough to reach over from one contact to the next, so that there should be no break in the continuity of the current supplied to the motor. The collector is a long strip of phosphor bronze fixed to a length of hose-pipe carried on a beam, which in its turn is suspended from the car axles. This method of attachment allows considerable freedom of vertical movement

and ensures a steady contact pressure, while getting rid of the constant oscillation which would result from suspending the apparatus from the car body. At each side of this collector, throughout its length and extending some 18 inches beyond it at each end, there are two longitudinal iron bars, in sections which are magnetised by six electro-magnets, all arranged in the same way so as to make one bar a north pole throughout and the other a south pole. These bars come down to within about an inch of the level of the studs and the contact bar, so that so long as they are over the studs a very strong pull is exerted on the magnetic parts in them. There are two reasons for having the magnets longer than the collector, namely, first, that the carbon switch in the contact box is never allowed to break the main current, as the switch is held up for an appreciable time after the collector strip has left the contact; and, secondly, that the leading end of the magnet poles pulls up the switch and makes the contact there alive before the collector reaches it. This is rendered necessary owing to what is known as the "time element" in such gear, *i.e.* the fact that it does not respond instantaneously, which has given a good deal of trouble in other surface-contact systems.

The street-contact plate consists of three parts; the centre is of manganese steel, ribbed and rounded off, which is non-magnetic and exceedingly hard, while the two pieces on either side are of cast-iron, the whole being virtually cast-welded together. When the car passes the two long poles run over the two cast-iron pieces, which are of course not magnetically short circuited or affected by the centre non-magnetic piece. But in action the magnetic circuit is completed (excepting for the two small air gaps of about 1 inch each at street level) by an iron keeper or armature inside the switch-box, which rises up, and in so doing connects the stud to the live mains. This it does by means of carbon contacts, which (as already explained) make the circuit alive before any current is required, and do not break it until after the current has ceased to be drawn from the stud.

The actual size of the street contact plates is $12\frac{1}{2}$ inches by $6\frac{3}{4}$ inches, and they are placed 10 feet apart centre to centre, the top of the plates being some $\frac{3}{4}$ inch above the rails. They with the switch gear are laid in a material known as reconstructed granite, which appears to be one of the very best insulators for hard wear. It is made by breaking up and calcining granite, mixing it with a certain amount of felspar and kaolin and some water, and then moulding it under heavy pressure. After preliminary drying it is fused into a

homogeneous mass in furnaces and a vitrified glazing is added, which renders it entirely non-porous, practically fire-proof and highly insulating, coupling these qualities with great strength. Blocks of this material are used then for carrying the contact studs and their gear. There is a thin layer of insulating material (bitumenous), interposed between the pieces and also round the holding-down bolts, and the cables are run up to their connection entirely on the solid system from the Callendar troughs below. The actual contacts, and the iron armature that actuates them, are enclosed in a double cup of an insulating material called vulcabeston, the current being conveyed up by a copper spring.

The two long magnetic poles run about 1 inch above the surface contacts, and this air gap, together with that inside the switch, makes it necessary to use powerful magnets. The poles cannot safely be brought lower, and, even as it is, there is a danger of stones catching them, so this is perhaps rather a weak point. It also appears that there is a good deal of sheet iron dropped about the road from the waste cuttings being removed from works, and these give some trouble by clinging to the poles. The magnets have two separate windings; the normal one a shunt across the 500 volts, all coils being in series, while the other set of coils carry the main current on its way to the motors, and so strengthen the field and increase the contact pressure of the switch while current is actually passing through them. The thick wire winding can be used at starting, to pick up the first contact, by means of a small six-cell battery, which can only be put in when the main current is not running in the coils.

The remaining equipment of the system does not call for any particular comment, as it is on the ordinary lines already laid down. The maximum speed has been fixed by the Board of Trade at eight miles an hour and at facing points four miles an hour. The system has already had some trouble from snow, but no new system becomes perfectly successful at the first start off.

Central London Railway.

As an example of railway work I will give you some further details about the Central London Railway, generally known as the "twopenny tube." The line runs out some 5¾ miles from the heart of the City, having 13 stations altogether, and the line is carried in two tunnels side by side far down below the streets and their complement of pipes, wires, sewers,

and ordinary undergound railways. Passengers are taken up and down at the stations in large electric lifts, and the whole system is worked so as to avoid delays of all sorts. There is a very rapid service of trains—about two minutes' headway being allowed—the speed, acceleration and retardation are high, and the stops are reduced to the utmost. The construction of the line was begun in 1895 and completed in 1900. The power-station is at the extreme outer end of the line, at Shepherd's Bush; current is there generated 3-phase at 5,000 volts, transmitted to sub-stations along the line, and there transformed down to 550 volts (continuous current) on the feeders. Ultimately the third rail is fed at 500 volts just as in most other cases. The depôt at the terminus contains the engine and carriage sheds, repair shops, stores, and generating station, occupying a considerable portion of the 20 acres enclosed in.

Boiler-house.—The boiler-house has some 20 Babcock. and Wilcox water-tube boilers, working at 160 lbs. pressure. In a large station like this it is of course of the greatest importance to reduce the labour of handling as far as possible, wherever machinery can be employed instead, for power is available and cheap. Complete arrangements are consequently made for running the coal from the trucks on the railway siding to the boiler-house, where a mechanical conveyer takes it and delivers it into the bunkers over the stokers. The conveyer is a great endless chain band, running over the boilers and back under the boiler gangway. On this revolving band, which is electrically driven by an 8 H.-P. motor at 40 feet a minute, are 200 buckets, each arranged to take 1 cwt. of coal normally. At any one time 20 full buckets are being lifted, while the rest are travelling along above or below. In this way some 150 tons an hour can be put into the bunkers, which will hold altogether 1,000 tons, or a week's supply. From the bunkers into the stoker hoppers the coal runs down by gravity, regulated by hand from the gangway. Vicars' mechanical stokers are used; this is an arrangement by which the firebars are in two alternate sets, driven by a small engine in such a way as to carry the coal steadily forward towards the bridge. One set of bars rises a little, travels forward with the fuel, and then drops down again, leaving the fuel resting on the other set of bars as they rise in turn to go through the same cycle. The mechanical stokers are driven by Chandler high-speed engines, geared down to give the required slow movement of the bars. Any stoker can be cut off at will if required. The feed water for the boilers is

heated up by four Green's economisers, each of 768 tubes. These are placed vertically in a chamber between the boilers and the chimney, so that the furnace gases pass among them and heat up the contained water. In order to prevent the deposition of soot from acting as an effectual non-conductor, scrapers are arranged on each tube, which are moved slowly up and down by chains actuated by a motor above; each pair of economisers requiring a 5 H.-P. motor. There are two chimneys, each 10 feet internal diameter and 250 feet high.

Engine-room.—There are six main sets, each of 850 kilowatts at 5,000 volts 3-phase, direct coupled to horizontal cross-compound Allis engine, with Corliss valve gear. Cylinders are 24″ and 46″, stroke 4 feet, governing is effected on the cut off of each cylinder, and there is an emergency governor as well. The generators are of the revolving field type, and at 94 revolutions generate 3-phase at 25 cycles per second. The revolving field consists of 32 outwardly-projecting laminated poles and magnet cores, bolted to a cast-steel ring. This ring is carried by a heavy cast-iron spider, which is mounted on the extended engine shaft between the high and low-pressure cranks. The armature is built up outside the revolving magnets, with a clearance of $\frac{1}{3}$ inch. It is of the slotted type, and the coils are former wound and easily removed should repairs be necessary. Each engine has its own Allis jet condenser, and at the time I visited the station these were giving a lot of trouble. There is, however, an auxiliary condensing plant of a different type and independently worked. For the excitation of the large generators separate continuous current combined sets are provided, and others again for lighting, etc , in the works.

Feeders.—The 5,000 volt 3-phase current is taken out in four separate 3-core cables. These are paper-insulated and lead-covered, and tested to 15,000 volts; two are carried in each tunnel, and they are supported on brackets attached to the tunnel rings and covered in by an iron shield. There are three sub-stations—at Notting Hill Gate, Marble Arch, and the General Post-office. The copper section of each cable is ·1875 square inch up to the first sub-station, and after that is ·125 square inch to the other two. In all there are some 78 tons of copper used in these high-tension cables.

Sub-stations —Each sub-station has seven stationary transformers, each of 300 kilowatts capacity, two rotatory converters, each of 900 kilowatts capacity, switch gear, and two blowers for forcing air through the static transformers.

These latter transform down from 5,000 volts to 330 volts; the output of the converters is 900 kilowatts at 500 volts (continuous current) normally, the corresponding alternating input being 305 volts. The third rail is fed from the positive bus bars of the sub-stations, this rail being normally divided up into sections at these points. Arrangements are made, however, by which all the line can be fed from any one or two sub-stations if repairs are going on. At each station there are electric lifts for taking passengers up and down to the line, and these, together with the lighting arrangements at the subterranean stations, are worked from the low-tension mains. Batteries are installed for use on these circuits when the power is cut off.

The line.—A single tunnel runs down from the depôt at Shepherd's Bush to the working lines at the first station. In the tunnels the track-rails are of the bridge section shown in figure 53, while the insulated third-rail conductors are

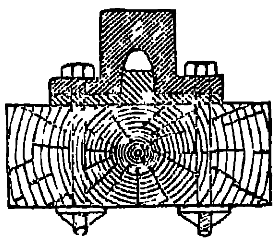


Figure 53.—C. L. R. track rails.

of inverted channel steel supported on special insulators of porcelain. There are some 14½ miles of third rail and

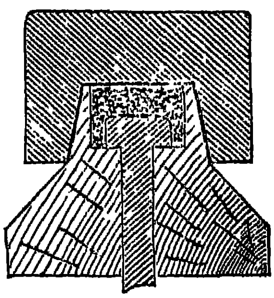


Figure 54.—C. L. R. third rail.

9,000 of the insulators altogether. The third rail has quadruple copper bonds at the joints, and each track-rail has duplicate bonds, one each side of the rail.

Tunnels and gradients.—I have already briefly described the way in which the Greathead tube system is worked for the tunnels. These are placed side by side as a rule, but in some cases one is vertically over the other. They are 11 feet 6 inches in diameter, and while running level most of the way all the stations are super-elevated, in order to utilize the switchback principle at starting and stopping. The stations themselves are level, but in coming into them the trains have to run up an incline of generally 1·66 per cent., which helps in retarding. On starting, just outside the station there is a down grade of 3·3 per cent., which assists in getting up speed rapidly by invoking the aid of gravity. Thus excessive current at starting and excessive waste from braking at stopping are alike avoided, and the momentum of the train which is absorbed when rising into a station is ready to be given out again on the descending grade beyond, which results in very great economy.

Rolling-stock.—I have already given a brief description of the locomotives used (page 20). The four 117 H.-P. motors are mounted direct on the axles; but owing to vibration troubles, experiments are now being made with separate motors on each carriage of a train in order to distribute the load more evenly and to prevent the great jolt at present inevitable when running over a joint. The average current per train throughout the run, including stops, is 170 or 180 ampères at 500 volts. As there are some 22 trains in service at one time out of the total of 24, the average output from the rotatary converters for running trains is about 4,000 ampères, and the lifts and lights at all the stations probably account for another 1,400 ampères. The maximum total is about 8,000 ampères.

High-pressure, High-speed Experimental Railway.

Amongst other particularly interesting novelties shown to those of us who went to Germany last year, the experimental military railway took a high place. A short length of line was equipped near Berlin at Gross-Lichterfelde, chiefly for seeing how the overhead equipment worked at the high pressure used. The line was designed for a speed of about 35 miles an hour, but a further line is under consideration on which a speed of 125 miles an hour will (it is believed) be attained.

The supply is 3-phase at 10,000 volts on the overhead line and a frequency of 50 cycles per second. Where heavy traffic on ordinary lines of railway is to be electrically worked, a high rate of transmission of energy into the cars is necessary, and at the ordinary low pressure this would involve the use of very heavy trolley wires and the collection of very heavy currents from them. If the employment of extra high pressure for the overhead line and the collection of current at this pressure on the car or locomotive does not entail too great expense and danger in comparison with stationary transformers along the line, it is obvious that there are great advantages, since the collection of a large current from a wire always offers difficulty.

A voltage of 10,000 volts 3-phase is used, this being delivered direct to the locomotive, where it is transformed down before feeding the motors. The current is led along three overhead conducting wires slung in one vertical plane from posts; the lowest is 18 feet; the second $21\frac{1}{4}$ feet, and the third $24\frac{1}{2}$ feet from the ground. The insulators are attached to a somewhat loose vertical rope or chain about 11 feet long and attached to the top and bottom ends of a bow fastened to the upright post. The object of attaching them loosely is to give independent flexibility to the contacts with the three bow current collectors, which swing upon vertical hinged spindles on the roof of the locomotive.

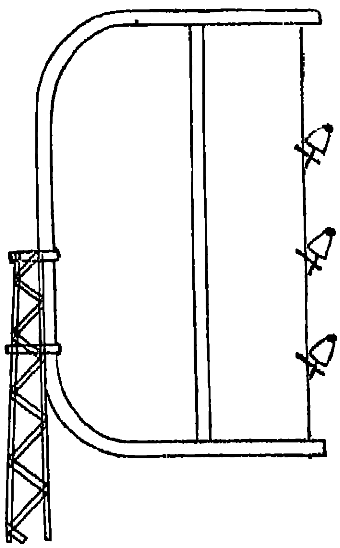


Figure 55.—Conductors on three-phase high-pressure railway.

The actual collecting part of each bow is vertical instead of horizontal as usual, and the bows are placed one behind the other with a space between each, so that they have small chance of fouling one another. The three overhead lines too are placed clear at the side of the track, with a net running all along to catch a broken wire. The bows are made of aluminium to lessen their mass, and thus make them obey more quickly the spring pressure which thrusts them sidewise against the line conductors. Two static transformers, permanently grouped in star-winding, and lying horizontally inside the locomotive, transform the current to the lower tension of 750 volts. The conductors down to the transformers are heavily insulated, and are led down inside an iron tube for protection, which, together with all the iron construction of the locomotive, is well earthed. The locomotive carries two asynchronous three-phase motors, each of 30 normal and 120 maximum horse power. These are geared to the driving axles in the ratio of 1 to 3·15, and as the wheels have a diameter of 39 inches, this gearing gives at normal horse-power a speed of 60 kilometres (33 miles) per hour. The rail gauge is 4 feet 8½ inches; the wheel base 9 feet, and the total weight of the experimental locomotive 16 tons. The roof of the car carries three horn lightning arresters. The controller effects variations in the speed by changing the connections of the transformer secondaries. It makes star connection for full speed at normal horse-power, mesh connection for maximum horse-power, when a large tractive effort is required, and for half speed places one of the secondary phases on open circuit. The starting and regulating rheostats are on the secondaries, and are of the sheet-iron type enclosed in sheet-iron cases. Hand-brakes as well as Westinghouse air-brakes are fitted, the two air compressors being motor driven. These motors are fed by current from a small auxiliary transformer, giving out current at 1,000 volts. The high-pressure switches are of the tube form and are placed in the roof of the car. They are actuated by air pressure, making contact when the air is admitted and breaking it when the air is exhausted from the cylinders. The break is at two points, and, when fully opened, the two air gaps together have a total length of 12 inches.

Now, as the feasibility of collecting at extra high pressure is proved, the new line for extra high speed also is being considered. The cars are already under construction and the collecting arrangements are to be very similar.

For the high speed of 125 miles per hour, it is intended to use 2,000 volts in the primaries of the motors during starting when these are connected in star-winding, and 1,150 volts during normal running on a mesh-winding, the transformers on the car having a 5 to 1 ratio for reducing the extra high pressure. Each motor will then have 250 normal and 1,000 maximum horse-power, and will run at 880 revolutions per minute, with a frequency of 45 cycles per second. The primary current is to be led into the rotor, or revolving part of the machine, by three slip rings, and the secondary current is induced in the stator.

For such a speed as is proposed it is essential that the track shall be laid with the utmost care, and the trucks also need to be specially designed. One was shown us in course of construction.

London Tramways.

The whole of the tramways of London were until very recently worked by horses, with the exception of a short length of cable haulage up a steep hill. At present the London County Council are about to equip their lines electrically on the conduit system, and the London United Tramway Company have already started running some of their lines on the overhead system, while more are undergoing reconstruction. It is these latter that I will give a short description of. Some 7½ miles were running when I was there last year, starting from near the Shepherd's Bush terminus of the Central London Railway and running out to Kew Bridge.

Power-house.—Continental nations build their electric stations so that they are a pleasure to see, and they are almost prodigal of space and ornamentation. In this respect the London tramways have rivalled them, for the power-station at Chiswick is a most handsome building. There are 10 Babcock and Wilcox boilers, each capable of evaporating 11,000 lbs. of water per hour at 150 lbs. pressure. There are automatic stokers and coal conveyers, the latter being used also to remove the ashes, and there is a Green's economiser ; I have already described these. The chimney stack is of somewhat novel construction, being built of steel plates for the top 200 feet of its 260 feet total height. These are in the form of rings, lap-jointed and riveted together, and springing from a base plate of cast-iron bolted to the concrete foundations.

The generating plant for running the lines near the power-station consists of two vertical cross-compound condensing Allis engines, with cylinders 22 inches and 44 inches and 42 inches stroke running at 90 revolutions per minute. The flywheel weighs some 36 tons, and the actual speed variation does not exceed $2\frac{1}{2}$ per cent. from no load to full load. Each engine is direct coupled to two 250 kilowatt continuous current generators, placed one on either side of the flywheel. This is because it was intended at first to use the 3-wire system, with 1,050 volts between the outers and the rails for the third wire, but this has been abandoned.

For the more distant parts of this extensive system 3-phase transmission is to be used. There are in course of erection two 1,000 kilowatt sets and one 500 kilowatt set. These sets generate at 5,000 volts with a frequency of 25 cycles per second. The machines have revolving fields, excited from the continuous current bus bars.

Switchboards.—The continuous current switchboard consists of four generator panels, two panels for 15 kilowatt negative boosters, eight feeder panels, a Board of Trade and an instrument panel. The high-tension board contains three 3-phase generator panels and eight 3-phase feeder panels. The switches for the high-tension side are placed in a separate chamber and are operated by levers from the switchboard.

The lines.—Only a short length of line is actually running yet, and this is nearly all span wire work. The side poles are of three grades, able, when set 6 feet in the ground, to stand strains of 700 lbs., 1,000 lbs., and 1,500 lbs. respectively, applied 30 inches from the top, with a temporary deflection of not more than 6 inches. The trolley wire is hard-drawn copper wire No. 0 S.W.G. The maximum working stress will not exceed 2,000 lbs. and the breaking strain is 5,000 lbs. There are 42 main feeders, paper insulated and lead covered and on the draw-in system, all being in duplicate. There are distributing or sub-feeders in parallel with the lines throughout, feeding the half-mile sections and themselves fed about every $1\frac{1}{2}$ miles. Return feeders of $\frac{1}{2}$ square inch section run back from two points to the boosters. The lead covering of all the cables is connected to the track and the metal pipes. The rails are grooved girders weighing $92\frac{1}{2}$ lbs. per yard, and each pair of fish plates weighs $92\frac{1}{2}$ lbs. Double bonds No. 0000 Brown and Sharpe gauge are used, with cross bonds every 40 yards.

APPENDIX I.

GOVERNMENT OF INDIA

ELECTRIC LIGHTING AND TRACTION RULES.

UNDER SECTION 4 OF ACT XIII OF 1887.

Revised 12th July 1901.

NOTE.—These rules have superseded both the Government of India rules of 3rd December 1897 and the "A" regulations of the Government of Bengal, dated 15th February 1898.

PRELIMINARY.

Difinitions.

1. In these rules, unless there is anything repugnant in the subject or context,—

(1) the expression "current" means an electric current exceeding one-thousandth part of one ampére;

(2) the expression "electric supply-line" means a wire or wires, conductor, or other means used for the purpose of conveying, transmitting, or distributing, energy for light or power, together with any casing, coating, covering, tube, pipe or insulator enclosing, surrounding or supporting the same or any part thereof, and any apparatus connected therewith for the purpose of conveying, transmitting or distributing energy or electric currents for light or power;

(3) the expression "energy" means electrical energy expended at a rate greater than one watt;

(4) the expression "street" includes any way, road, lane, square, court, alley, passage or open space, whether a thoroughfare or not, over which the public have a right of way, and also the roadway and footway over any public bridge or causeway;

(5) the expression "undertakers" means the person or persons undertaking the businesss of supplying energy or intending to use energy for any public purpose or in any place such as is referred to in section 3 of the Indian Electricity Act, 1887;

(6) the expression "main" means any electric supply-line, which may be laid down by the undertakers, in any street or public place and through which energy may be supplied, or intended to be supplied by the undertakers, for the purposes of general supply, and includes a feeder and a distributing main;

(7) the expression "feeder" means a portion of any main used to convey energy from the source of supply to the point or points where it is distributed for use;

(8) the expression "distributing main" means the portion of any main which is used for transmitting energy to service lines for the purposes of general supply;

(9) the expression "service line" means any electric supply-line through which energy may be supplied, or intended to be supplied by the undertakers, to a consumer either from any main or directly from the premises of the undertakers;

(10) the expression "cut-out" means any appliance for interrupting the transmission of energy through any conductor when the current rises above the amount which the conductor is intended to transmit and includes a safety fuse or other automatic disconnector;

(11) the expressions "transformer," "transformed" and "transforming" are used in relation to any appliance by means of which electricity of higher potential is converted to electricity of lower potential, or *vice versâ;*

(12) the expression "consumer's wires" means any electric conductors on a consumer's premises which are connected with the service lines of the undertakers at the consumer's terminals;

(13) the expression "aèrial line" means any electric supply-line which is placed above ground and in the open air;

(14) the expression "pressure" means the difference of electric potential between any two conductors through which a supply of energy is given, or between any part of either conductor and the earth;

(15) the expressions "pressure," "high pressure" and "extra high pressure" are used in relation to electric supply-lines, conductors, circuits and apparatus according to the conditions of the supply delivered through the same or particular portions thereof;

(16) where the conditions of the supply are such that the pressure may at any time exceed 500 volts, if continuous, or 250 volts, if alternating, but cannot exceed 3,000 volts whether continuous or alternating, the supply shall be deemed to be a "high pressure supply;"

(17) where the conditions of the supply are such that the pressure may, on either system, exceed 3,000 volts, the supply shall be deemed to be an "extra high pressure supply;"

(18) the expression "generator" means the dynamo or dynamos or other electrical apparatus used for the generation of energy;

(19) the expression "motor" means any electric motor used for the conversion of energy; and,

(20) where these rules require any metallic body to be "efficiently connected with earth," it shall be connected with the general mass of earth in such manner as will ensure at all times an immediate and safe discharge of energy.

Protection of Person and Property.

Entry and inspection.

2. (1) Whenever notice has been given by the undertakers under section 3 of the Indian Electricity Act, 1887, the District Magistrate or, in a Presidency-town, the Commissioner of Police, shall, on receiving such notice, forthwith report the circumstance to the Local Government, and the Local Government may thereupon authorize any officer to enter, inspect and examine any place, carriage or vessel in which the officer has reason to believe that there are any appliances or apparatus used in the generation or supply of electricity, and any building or place to or in which electricity is being, or is to be, supplied or used.

(2) The undertakers shall afford at all times all reasonable facilities to any officer, duly authorized by the Local Government, to make such inspections and tests as may be necessary to ensure the due observance

of the rules hereinafter contained, and shall, if and when required, forward to such officer all records of tests hereinafter specified to be made and recorded.

Overhead electric supply-lines.

3. The Local Government shall, if necessary, instruct the District Magistrate, or, in a Presidency-town, the Commissioner of Police, as to the streets in which overhead electric supply-lines are not to be allowed, and the undertakers shall attend to any orders of such officer in this respect.

Testing appliances, etc.

4. The undertakers shall provide all means for testing the appliances or apparatus used in the generation of the supply and use of energy.

Pressure of supply to consumers.

5. The pressure of a supply delivered to any one consumer shall not exceed 250 volts at any two terminals, within six feet of each other, and not under the sole control of the undertakers, except with the express approval of the Local Government, which shall be given only for special purposes on the joint application of the consumer and the undertakers and subject to such further condition as the Local Government may prescribe.

Pressure of supply to transforming apparatus.

6. The pressure of a supply delivered to a transforming station or to a transforming apparatus on a consumer's premises may exceed 250 volts, but shall not exceed the limits of high pressure.

Limitations of extra high pressure supply

7. An extra high pressure supply shall not be delivered, except to distributing stations or other premises in the sole occupation of the undertakers, and then only with the written consent of the Local Government and subject to such further conditions as that Government may prescribe.

Maximum current in conductors.

8. The maximum working current in a conductor shall not be sufficient to raise the temperature of the conductor, or any part thereof, to such an extent as to materially alter the physical condition or specific resistance of the insulation covering (if any) or in any case to raise such temperature to a greater extent than 33°F. The cross-sectional area and conductivity at joints shall be sufficient to avoid local heating, and the joints shall be protected against corrosion.

Minimum size of conductors.

9. The sectional area of the conductor in an electric supply-line laid or erected in any street after the commencement of these rules shall not be less than the area of a circle of one-tenth of an inch diameter, and, where the conductor is formed of a strand of wires, each separate wire, shall be at least as large as No. 20 standard wire gauge.

Specification and protection of insulating materials.

10. All material used for insulating electric supply-lines or apparatus shall be of the best quality and thoroughly durable and efficient with regard to the conditions of its use. Suitable provision shall be made for the protection of the insulating material against injury or removal, and, if the protection so provided is wholly or partly metallic, it shall be efficiently connected with earth.

11. Every main shall be tested for insulation after having been placed in position and before it is used for the purposes of supply, the testing pressure being at least the declared working pressure, and the undertakers shall duly record the results of the tests of each main or section of a main or distributing main.

Insulation test of mains.

12. (1) The insulation of every complete circuit used for the supply of energy, including all machinery, apparatus and devices forming part of, or connected with, such circuit, shall be so maintained that the leakage current shall not under any conditions exceed one-thousandth part of the maximum supply current. Suitable means shall be provided for the immediate indication and localisation of leakage, and every leakage shall be remedied without delay. Every such circuit shall be tested for insulation at least once in every week, and the undertakers shall duly record the results of each test.

Maintenance of insulation.

(2) Nothing in this rule shall apply to the use of energy generated upon premises occupied by the person using the same, or, where the Local Government has approved of any part of an electric circuit being connected with earth, to that circuit so long as such connection exists.

13. Within the limits of a municipality, and elsewhere within such limits as may be prescribed by the Local Government, every high pressure conductor laid after the commencement of these rules shall be continuously covered with insulating material of requisite thickness. When the material used is India-rubber, it shall be not less than one-tenth part of an inch in thickness and in cases where the extreme difference of potential in the circuit exceeds 2,000 volts, the thickness of such insulating material shall not be less in inches or parts of an inch than the number obtained by dividing the number expressing the volts by 20,000.

High pressure conductor to be covered.

14. No high pressure circuit shall be brought into use unless the insulation of every part thereof has withstood the continuous application during one hour of pressure exceeding the maximum pressure to which it is intended to be subjected in use; that is to say, in the case of every electric supply line, a pressure twice the said maximum pressure, and in the case of every machine, device or apparatus, a pressure 50 per cent. greater than the said maximum pressure. The undertakers shall duly record the results of each test.

Testing of insulation of all parts of any high pressure circuit.

15. Every high pressure electric supply-line, conductor or other apparatus shall be protected by a suitable automatic quick-acting cut-out:

Quick-acting cut-out for high pressure electric supply-lines, etc.

Provided that it shall not be incumbent upon the undertakers to provide such a cut-out for the outer conductor of a concentric main which is, with the approval of the Local Government, efficiently connected with earth.

16. In every case in which a high pressure supply is transformed for the purpose of supply to one or more consumers, some suitable automatic and quick-acting means shall be provided to protect the consumer's wires from any accidental contact with, or leakage

Safety devices for the protection of consumer's wires.

from, the high pressure system, either within or without the transforming apparatus.

Limit of power in high pressure electric supply-lines.

17. A high pressure electric supply-line shall not be used for the transmission of more than 300,000 watts, except with the consent in writing of the Local Government, and efficient means shall be provided to prevent this limit being at any time exceeded.

Protection from lightning.

18. Where any portion of an electric supply-line or any support for an electric supply-line is exposed in such a position as to be liable to injury from lightning, it shall be efficiently protected against such injury.

Accidents to be reported.

19. The undertakers shall give immediate notice to the Local Government of the occurrence, at any part of an electric supply-line or work of any accident by explosion or fire or of any other accident causing or likely to cause loss of life or personal injury.

Aërial Lines.

Limit of power in aërial lines.

20. Where the use of aërial lines has in any case been sanctioned, the Local Government may, with due regard to climatic conditions, determine the maximum limit of power which is to be transmitted by any such line or system of lines carried on a single alignment of supports in any street, and efficient means shall be taken to prevent this limit being at any time exceeded.

Maximum intervals between supports.

21. Every aerial line shall be attached to supports at intervals not exceeding 200 feet, where the direction of the line is straight, and 150 feet, where the direction is curved or where the line makes a horizontal angle at the point of support:

Provided that the Local Government may, by order in writing, permit any modification of this rule which it considers necessary by reason of local conditions.

Construction and erection of supports.

22. Every support of an aërial line shall be of a durable material, and properly stayed against forces due to wind pressure, change of direction of the line or unequal lengths of span. The factor of safety shall be for aèrial lines and suspending wires at least six, and for all other parts of the structure at least twelve, the maximum possible wind pressure being taken at 50lbs. per square foot. No addition need be made for a possible accumulation of snow. Every support, if of metal, shall be efficiently connected with earth.

Attachment of aërial lines.

23. Aèrial lines, other than trolley wire for tramcars, cranes or other appliances taking power from rubbing contacts, shall be attached to insulators, and shall be so guarded that they cannot fall away from the support. Conductors covered with insulating material shall be attached to the insulators by such means as shall prevent the insulation being damaged.

24. (1) Except as otherwise directed in rules 74 and 75, no part of any aerial line shall be at a less height from the ground than 18 feet, or where it crosses a street, 30 feet, or within 5 feet measured horizontally or 7 feet measured vertically from any building or erection other than a support for the line, unless it has been brought into a building for the purpose of supply:

Height from ground and distance from buildings, etc.

Provided that the Local Government may, by order in writing, permit any modification of this rule which it considers necessary.

(2) Except with the approval of the Local Government and of the telegraph authority, aerial lines shall be carried along only one side of a street.

(3) Nothing in sub-rule (1) shall apply to the use of energy generated upon premises occupied by the person using the same.

25. (1) Service lines from aërial lines shall be led as directly as possible to insulators firmly attached to some portion of the consumer's premises and at a distance not less than 5 feet therefrom. Such service lines shall not be accessible to any person without the use of a ladder or other special appliance, and from this point of attachment they shall be enclosed and protected in accordance with the rules hereinafter contained as to electric conductors on the consumer's premises.

Service lines from aerial lines.

(2) Nothing in this rule shall apply to the use of energy generated upon premises occupied by the person using the same.

26. (1) Where an aerial line crosses a street, the angle between the line and the direction of the street at the place of crossing shall not be less than 60°. Where the width of the street exceeds 30 feet, a support shall be erected on each side of it, and the space between such supports shall be as short as practicable.

Angle of crossing thoroughfares.

Saving.

(2) Nothing in this rule shall apply to energy generated upon the premises occupied by the person using the same.

27. Where an aerial line crosses, or is in proximity to any metallic substance, adequate precautions shall be taken by the undertakers against the possibility of the line coming into contact with the metallic substance or of the metallic substance coming into contact with the line by breakage or otherwise.

Crossing wire, etc.

28. Every high pressure aerial line required by rule 13 to be continuously covered with insulating materials shall be efficiently suspended by means of insulating ligaments to suspending wires, so that the weight of the line may not produce any sensible stress in the direction of its length. All suspending wires, if of iron or steel, shall be galvanised.

Suspending wires.

29. In the case of any high pressure aërial line exceeding one-half of a mile in length, means shall be provided whereby the pressure may be discharged from any portion of the line erected over, or alongside of, any building or buildings without loss of time in case of fire or other emergency.

Discharge of pressure in case of fire.

30. Every aerial line, including its supports and all the structural parts and electrical appliances and devices belonging to, or connected with, the line, shall be duly and efficiently supervised and maintained as regards both electrical and mechanical conditions

Maintenance.

31. High pressure and low pressure aerial lines shall in no case be carried on the same supports within the limits of a municipality, and outside such limits shall be so carried only with the special permission of the Local Government. Wherever a high pressure aerial line crosses a low pressure aerial line, or *vice versâ*, the provisions of rule 27 shall apply.

High pressure and low pressure aërial lines not allowed on same supports.

32. An aerial line shall not be permitted to remain erected after it has ceased to be used for the supply of energy, unless the undertakers intend within a reasonable time again to take it into use.

Unused aerial lines to be removed.

ELECTRIC SUPPLY-LINES OTHER THAN AERIAL LINES.

33. All conduits, pipes, casings and street-boxes used as receptacles for electric supply-lines shall be constructed of durable material, and, where laid under carriage-ways, shall be of sufficient strength to prevent damage from heavy traffic; and reasonable means shall be taken by the undertakers to prevent the accumulation of gas in such receptacles.

Construction of receptacles for electric supply lines.

34. Where an electric supply-line crosses, or is in proximity to, any metallic substance, special precautions shall be taken by the undertakers against the possibility of any electrical discharge to the metallic substance from the line or from any metal conduit, pipe or casing enclosing the line.

Crossing pipes, etc.

35. All metal conduits, pipes or casings containing any electric supply-line shall be efficiently connected with earth, and shall be so jointed and connected across all street-boxes and other openings as to make good electrical connection throughout their whole length.

Electric continuity of metal conduits, pipes or casings.

36. Where isolated lengths of metal conduits, pipes or casings are used for the protection of any electric supply-line at road crossings or in similar positions, special precautions shall be taken to prevent the possibility of any electrical charging thereof.

Precautions against charging of short lengths of pipes, etc.

37. (1) Where the conductors of electric supply-lines placed in any conduit are not continuously covered with insulating material, they shall be secured in position, and no unfixed uninsulated material of a conducting nature shall be contained in the conduit. No such conductor shall be at a higher potential than 300 volts.

Precaution to be taken when bare conductors are used.

(2) Adequate precautions shall also be taken to ensure that no accumulation of water shall take place in any part of the conduit, and to prevent any dangerous access of moisture to the conductors or the insulators.

(3) In the case of any such electric supply-lines laid in conduits after the commencement of these rules, the insulators shall be so disposed that they can be readily inspected.

High-pressure electric supply-lines laid above ground.

38. Every portion of a high-pressure electric supply-line placed above the surface of the ground, or in any subway not in the sole occupation of the undertakers, shall be completely enclosed either in a tube of highly insulating material embedded in brickwork, masonry or cement concrete, or in a strong metal casing efficiently connected with earth.

High-pressure electric supply-lines laid in proximity to other electric supply-lines or to the surface of the ground.

39. Where a high-pressure electric supply-line is laid beneath the surface of the ground, efficient means shall be taken to render it impossible that the surface of the ground or any neighbouring electric supply-line or conductor shall become charged by leakage therefrom.

Street-Boxes.

Street-boxes.

40. In addition to the provisions contained in rule 33 as to the construction of receptacles for electric supply-lines, the following rules shall be observed with respect to the construction of street-boxes:—

(*a*) The cover of every street-box shall be so secured that it cannot be opened except by means of a special appliance.

(*b*) The covers of all street-boxes containing high-pressure apparatus other than cables shall be connected with strips of metal laid immediately underneath the adjacent roadway, and efficient means shall be taken to render it impossible that the covers or other exposed parts of such boxes, or any adjacent material forming the surface of the street, shall become electrically charged, whether by reason of leakage, defect or otherwise.

(*c*) Where street-boxes are used as transformer chambers, reasonable means shall be taken to prevent, as far as possible, any influx of water either from the adjacent soil or by means of pipes; and in the case of any such street-box exceeding one cubic yard in capacity, ample provision shall be made, by ventilation or otherwise, for the immediate escape of any gas which may by accident have obtained access to the box, and for the prevention of danger from sparking.

(*d*) Every street-box shall be regularly inspected for the presence of gas, and, if any influx or accumulation is discovered, the undertakers shall give immediate notice to the authority or company whose gas mains are laid in the neighbourhood thereof.

Transforming Stations.

Transforming stations.

41. Transforming stations, or points, which are in a system of distribution wherein a high-pressure supply is transformed for the purpose of supply to consumers,

and which are not on a consumer's premises, shall be established in suitable places in the sole occupation and charge of the undertakers.

CONSUMER'S PREMISES.

Responsibility of undertakers for their conductors, etc., on consumer's premises.

42. The undertakers shall be responsible for all electric conductors, fittings and apparatus belonging to them or under their control, which may be upon a consumer's premises, being maintained in a safe condition and in all respects fit for supplying energy.

Fire risk.

43. In delivering the energy to a consumer's terminals the undertakers shall exercise all due precautions so as to avoid risk of causing fire on the consumer's premises.

Main fuses or disconnectors to be provided in locked receptacles

44. A suitable safety fuse or other automatic disconnector shall be inserted in each service line within a consumer's premises as close as possible to the point of entry and contained within a suitable locked or sealed receptacle of fire-proof construction throughout, and shall be under the sole control of the undertakers, except in cases where the service line is protected by fuses at the point of connection to the distributing main. If the receptacle is of porcelain or other substance liable to be easily broken, it shall be suitably protected against injury, and such protection shall also be fire-proof.

Treatment of electric conductors and apparatus on consumer's premises.

45. All electric conductors and apparatus placed on a consumer's premises shall be highly insulated and thoroughly protected against injury to the insulation or excess of moisture, and any metal forming part of the electric circuit shall not, unless efficiently connected with earth, be exposed so that it can be touched. All electric conductors shall be so fixed and protected as to prevent the possibility of electrical discharge to any adjacent metallic substance.

Transformers and high-pressure apparatus to be enclosed in metal.

46. Where the general supply of energy is a high-pressure supply and transforming apparatus is installed on a consumer's premises, the whole of the high-pressure service lines, conductors and apparatus, including the transforming apparatus itself, so far as they are on the consumer's premises, shall be completely enclosed in solid walls or in a strong metal casing efficiently connected with earth, and shall be securely fastened throughout.

Connections to consumers not to be made where leakage would result.

47. The undertakers shall not connect the wires and fittings on a consumer's premises of their mains unless they are reasonably satisfied that the connection will not cause a leakage from those wires and fittings exceeding one ten-thousandth part of the maximum supply current to the consumer's premises; and, where the undertakers decline to make such a connection, they shall serve upon the consumer a notice stating their reasons for so declining.

Discontinuance of supply on discovery of leakage on consumer's premises.

48. (1) If the undertakers are reasonably satisfied, after making all proper examination by testing or otherwise that a leakage exists at some part of a circuit of such extent as to be a source of danger, and that such leakage does not exist at any part of a circuit belonging to

the undertakers, then and in such case any person authorised in writing by the undertakers in that behalf, or, on the application of the undertakers, an officer authorised under rule 2, may, for the purpose of discovering whether the leakage exists at any part of a circuit within or upon any consumer's premises, after giving the consumer reasonable notice in writing, inspect and test the wires and fittings belonging to the consumer and forming part of the circuit.

(2) In any case in which the undertakers obtain the services of an officer under this rule, they shall pay him such fee as the Local Government may fix in that behalf.

(3) If, on testing in the manner referred to in sub-rule (1), such person or officer as aforesaid discovers a leakage from the consumer's wires exceeding one ten-thousandth part of the maximum supply current to the premises, or if the consumer does not give all due facilities for inspection and testing, the undertakers shall forthwith discontinue the supply of energy to the premises in question, giving immediate notice of the discontinuance to the consumer, and shall not recommence the supply until they are reasonably satisfied that the leakage has been stopped.

Appeal to officer appointed under rule 2.

49. (1) If any consumer is dissatisfied with the action of the undertakers in refusing to give or in discontinuing or in not recommencing the supply of energy to his premises, the wires and fittings of such consumer may, on his application and on payment of the prescribed fee, be tested for the existence of leakage by an officer authorized under rule 2.

2. This rule shall be endorsed on every notice given under the provisions of either of the two last foregoing rules.

ARC LIGHTING.

Arc lamps to be guarded.

50. All arc lamps shall be so guarded as to prevent pieces of ignited carbon or broken glass falling from them, and shall not be used in situations where there is any danger of the presence of explosive dust or gas.

Height from ground.

51. Arc lamps used in any street for public lighting shall be so fixed as not to be in any part at a less height than ten feet from the ground. Arc lamps used in any street for private lighting shall be fixed so as not to be anywhere at a less height than eight feet from the ground, and shall be so screened as to prevent risk of contact with persons.

Isolation switch.

52. An isolation switch, fixed in a suitable locked receptacle, shall be provided for every arc lamp on any high-pressure electric supply-line, and the switch shall be of such pattern and construction as will provide—

(a) that the lamp can by its means be entirely disconnected from the supply circuit;

(b) that the switch itself can be safely worked in the dark without special precautions; and

(c) that there shall be no danger of any injurious electrical arcing, sparking or heating being caused by the operation of the switch.

Rules for Electric Traction (Continuous Current).

53. Any dynamo used as a generator shall be of such pattern and construction as to be capable of producing a continuous current without appreciable pulsation.

Continuous current.

54. One of the two conductors used for transmitting energy from the generator to the motor and hereinafter referred to as the "line" shall be in every case insulated from earth. The other, hereinafter referred to as the "return," may be insulated throughout, or may be uninsulated in such parts and to such extent as is provided in the following rules. The suspended conductor from which energy is transmitted into any car is hereinafter referred to as the "trolley wire."

"Line" and "Return."

55. Where any rails on which cars run or any conductors laid between or within three feet of such rails form any part of a return, such part may be uninsulated. All other returns or parts of a return shall be insulated, unless of such sectional area as will reduce the difference of potential between the ends of the uninsulated portion of the return below the limit laid down in rule 59

Insulation of "Return"

56. When any uninsulated conductor laid between, or within three feet of, the rails forms any part of a return, it shall be electrically connected to the rails at distances apart not exceeding 100 feet by means of copper strips having a sectional area of at least one-sixteenth of a square inch, or by other means of equal conductivity.

Bonding of "Return."

57. (1) When any part of a return is uninsulated, it shall be connected with the negative terminal of the generator, and in such case the negative terminal of the generator shall also be directly connected, through the current indicator hereinafter mentioned, to two separate earth connections which shall be placed not less than twenty yards apart.

Return to be negative and earthed.

Provided that in place of such two earth connections the undertakers may make one connection to a main for water-supply of not less than three inches, internal diameter, with the consent of the owner thereof and of the person supplying the water.

Provided, also, that where, from the nature of the soil or for other reasons, the undertakers can show to the satisfaction of an officer appointed under rule 2 that the earth connections herein specified cannot be constructed and maintained without undue expense, the provisions of this rule shall not apply.

(2) The earth connections referred to in this rule shall be constructed, laid, and maintained so as to secure electrical contact with the general mass of earth, and so that the resistance from one earth connection to the other through the earth shall not exceed 2 ohms, and a test shall be made at least once in every month to ascertain whether this requirement is complied with.

(3) No portion of either earth connection shall be placed within six feet of any pipe, except a main for water-supply of not less than three inches internal diameter, which is metallically connected to the earth connections with the consent of the persons hereinbefore specified.

injurious affection, whether by induction, or otherwise, to such telegraph lines or the currents therein.

(2) Where any question arises as to whether the undertakers have constructed their electric supply-lines or other works, or worked their undertaking in contravention of this rule, it shall be determined by the Local Government, and the undertakers shall be bound to make any alterations in, or additions to, their system which may be directed by the Local Government.

Undertakers to be liable for injury to telegraph lines.

84. If any telegraph line referred to in rule 83 is injuriously affected by the construction by the undertakers of their electric supply-lines and works or by the working of the undertaking by the undertakers, the undertakers shall pay the expense of all such alterations in such telegraph lines as may be necessary to remedy such injurious affection.

Explanation.—A telegraph line shall be deemed to be injuriously affected by an act or work, if telegraph communication by means of such line is, whether through induction or otherwise, in any manner affected by such act or work or by any use made of such work.

Notice to telegraph authority in certain cases and compliance with telegraph requirements.

85. Before any electric supply-line is laid down or any act or work in connection therewith is done within 10 yards of any part of a telegraph line (other than repairs or the laying of lines crossing such telegraph line at right angles at the point of shortest distance and so continuing for a distance of six feet on each side of such point), the undertakers shall, not more than 28 nor less than 14 days before commencing the work, give notice in writing to the telegraph authority, specifying the course of the line and the nature of the work, including the gauge of any wire, and the undertakers shall conform with such reasonable requirements (either general or special) as may from time to time be made by the telegraph authority for the purpose of preventing any telegraph line from being injuriously affected by the said act or work.

Settlement of differences between telegraph authority and undertakers.

86. Where any difference arises between the telegraph authority and the undertakers with respect to any requirements of the telegraph authority, it shall be referred to the Local Government for decision, and the orders of the Local Government thereon shall be final.

Exemption in case of emergency.

87. Nothing in the four last foregoing rules shall apply to any case in which the undertakers can show that the immediate doing of the act or execution of the work was required to avoid an accident, or otherwise was a work of emergency, and that they forthwith served on the officer in charge of the Central Government Telegraph Office at the town or station where the act or work was done a notice in writing of the execution thereof, stating the reason for doing or executing the the same without previous notice.

Earth return current.

58. (1) Where the return is partly or entirely uninsulated, the undertakers shall, in the construction and maintenance of a tramway—

(*a*) so separate the uninsulated return from the general mass of earth and from any pipe, metallic structure or substance in the vicinity,

(*b*) so connect together the several lengths of the rail,

(*c*) adopt such means for reducing the difference produced by the current between the potential of the uninsulated return at any one point and the potential of the uninsulated return at any other point, and

(*d*) so maintain the efficiency of the earth connections specified in the preceding rules

as to fulfil the following conditions, namely—

(*i*) The current passing from the earth connections through the indicator to the generator shall not at any time exceed either two ampères per mile of single tramway line or 5 per cent. of the total current output of the station.

(*ii*) If at any time and at any place a test is made by connecting a galvanometer or other current indicator to the uninsulated return and to any pipe, metallic structure or substance in the vicinity, it shall always be possible to reverse the direction of any current indicated by interposing a battery of three Leclanche cells connected in series if the direction of the current is from the return to the pipe, metallic structure or substance, or by interposing one Leclanche cell if the current is in the reverse direction.

(2) In order to provide a continuous indication that the condition specified in clause (*i*) is complied with, the undertakers shall place in a conspicuous position a suitable, properly-connected, and correctly-marked current indicator, and shall keep it connected during the whole time that the line is charged.

(3) The owner of any pipe, metallic structure or substance in the vicinity of an uninsulated return may, in respect of the same, require the undertakers at reasonable times and intervals to ascertain by test in his presence or in that of his representatives that the conditions specified in clause (*ii*) are complied with.

Difference of potential on return.

59. Where the return is partly or entirely uninsulated, a continuous record shall be kept by the undertakers of the difference of potential during the working of the tramway between the points of the uninsulated return farthest from and nearest to the generating station. If at any time such difference of potential is found to exceed five volts, the undertakers shall thereafter make a daily report to the Local Government, or to such officer as the Local Government may authorise in this behalf, of the result of the previous day's test, and if at any time it exceeds the limit of seven volts, the undertakers shall take immediate steps to reduce it below that limit.

Provided that the Local Government may, in its discretion, modify the provisions of this rule in localities where it is unnecessary to enforce them:

Provided, also, that the limit of seven volts shall in no case be considered a figure to be worked up to in calculating the fall of potential due to the full conductivity of the return.

60. Every electrical connection with any pipe, metallic structure or substance shall be so arranged as to admit of easy examination, and shall be tested by the undertakers at least once in every three months.

Connection with pipes.

61. The line wire shall be divided up into sections not exceeding (except with the written approval of the Local Government) one-half of a mile in length, between every two of which shall be inserted an emergency switch, which apparatus shall be so enclosed as to be inaccessible to pedestrians.

Isolation of sections.

62. The insulation of the line and of the return when insulated and of all feeders and other conductors shall be so maintained that the leakage current shall not exceed one-hundredth of an ampère per mile of tramway. The leakage current shall be ascertained daily before or after the hours of running when the line is fully charged. If at any time it is found that leakage current exceeds one-half of an ampère per mile of tramway, the leak shall be localised and removed as soon as practicable, and the running of the cars shall be stopped unless the leak is localised and removed within twenty-four hours:

Leakage.

Provided that this rule shall not apply where both line and return are placed within a conduit.

63. The insulation resistance of all continuously insulated cables used for lines, for insulated returns, for feeders, or for other purposes, and laid below the surface of the ground, shall not be permitted to fall below the equivalent of ten megohms for a length of one mile. A test of the insulation resistance of all such cables shall be made at least once in each month.

Insulation.

64. Every insulated return shall be placed parallel to and at a distance not exceeding three feet from the line, when the line and return are both erected overhead, or eighteen inches when they are both laid underground:

Position of return.

Provided that the Local Government may permit any modification of this rule which it thinks fit.

65. In the disposition, connections, and working of feeders the undertakers shall take all reasonable precautions to avoid injurious interference with any existing telegraph lines.

Feeders.

66. The undertakers shall so construct and maintain their system as to secure good contact between the motors carried on the cars and the line and return respectively.

Maintenance of good contact.

Prevention of sparking.

67 The undertakers shall adopt the best means available for preventing undue sparking at any rubbing or rolling contact.

Rheostat.

68. In the working of the cars the current shall be varied as required by means of a rheostat containing at least twenty sections, or by some other equally efficient method of gradually varying resistance.

Conduit.

69. Where the line or return or both are laid in a conduit, the following conditions shall be complied with in the construction and maintenance of such conduit, namely:

(*a*) The conduit shall be so constructed—
(1) as to admit of easy examination of, and access to, the conductors contained therein and their insulators and supports;
(2) as to be readily cleared of accumulation of dust or other *débris*, and no such accumulation shall be permitted to remain.

(*b*) The conduit shall be laid to such falls and so connected to sumps or other means of drainage as to automatically clear itself of water without danger of the water reaching the level of the conductors.

(*c*) Where the conduit is formed of metal, all separate lengths shall be so jointed as to secure efficient metallic continuity for the passage of electric currents. Where the rails are used to form any part of the return, they shall be electrically connected to the conduit by means of copper strips having a sectional area of at least one sixteenth of a square inch or other means of equal conductivity, at distances not exceeding 100 feet. Where the return is wholly insulated and contained within the conduit, the latter shall be connected to earth at the generating station through a high-resistance galvanometer suitable for the indication of any contact or partial contact of either the line or the return with the conduit.

(*d*) Where the conduit is formed of any non-metallic material not being of high insulating quality and impervious to moisture throughout, and is placed within six feet of any pipe, metallic structure or substance, a non-conducting screen shall be interposed between the conduit and the pipe, metallic structure or substance, of such material and dimensions as shall provide that no current can pass between them without traversing at least six feet of earth, or the conduit itself shall in such case be lined with bitumen or other non-conducting, damp resisting material in all cases where it is placed within six feet of any pipe, metallic structure or substance.

(*e*) The leakage-current shall be ascertained daily, before or after the hours of running when the line is fully charged, and, if at any time it shall be found to exceed half an ampére

per mile of tramway, the leak shall be localised and removed as soon as practicable, and the running of the cars shall be stopped unless the leak is localised and removed within twenty four hours.

70. The undertakers shall, so far as may be applicable to their system of working, keep records as specified below These records shall, if and when required, be forwarded for the information of any officer authorized by the Local Government in this behalf

Records.

Daily Records.

Number of cars running

Maximum working current.

Maximum working pressure.

Maximum current from the earth connections [*vide* rule 58 (*i*)].

Leakage current [*vide* rules 62 and 69 (*c*)].

Fall of potential in return (*vide* rule 59).

Monthly Records.

Condition of earth connections (*vide* rule 57).

Insulation resistance of insulated cables (*vide* rule 63).

Quarterly Records.

Electrical connection of joints with pipes (*vide* rule 60).

Occasional Records.

Any tests made under provisions of rule 58 (*ii*).

Localisation and removal of leakage, stating time occupied.

Particulars of any abnormal occurrence affecting the electric working of the tramway.

71. Passengers shall not have access to any portion of the electric circuit having a greater difference of potential to earth than 100 volts.

Circuit to be inaccessible to passengers

72. All electric mains, leads and connections used in or upon any car shall be of ample size and thoroughly insulated and protected by safety fuses or other cut-outs which will operate to break the circuit before the current has risen to an amount which would cause any injurious heating of the conductors, and the length of every safety fuse in the clear shall not be less than two inches.

Connections on cars.

73. The electrical pressure or difference of potential between suspended conductors used in direct electrical connection with the working of the tramways by electrical power and the earth or between any two such suspended conductors, shall in no case exceed 500 volts continuous pressure.

Limit of pressure.

74. The trolley wire shall be in no part at a less height from the surface of the street than 17 feet, and shall be securely attached to supports, the intervals between which shall not, unless the Local Government otherwise directs, exceed 120 feet.

Height of conductors.

75. Where the feeders of any tramway are on the same supports as the trolley wire the provisions of rule 24 (1) shall not apply.

Height of feeders.

76. The sectional area of the conductor in any electric line laid or erected in any street after the commencement of these rules shall not be less than the area of a circle of one-tenth of an inch diameter, and, where the conductor is formed of a strand of wires, each separate wire shall be at least as large as No. 20 standard wire gauge:

Minimum size of conductors.

Provided that nothing in this rule shall apply to any electric line connected with the rails for the purpose of measuring the fall of potential in the return and not otherwise connected with the electric circuit.

77. No part of any electric line shall be used for the transmission of more than 300,000 watts, except with the consent in writing of the Local Government, and efficient means shall be provided to prevent this limit being at any time exceeded.

Limit of power.

78. All electrical conductors fixed upon the carriages in connection with the trolley wheel shall be formed of flexible cables protected by durable insulation of the highest quality, and additionally protected wherever they are adjacent to any metal so as to avoid risk of the metal becoming charged.

Conductors in connection with trolley wheel.

79. Every trolley standard shall be electrically connected with the wheels of the carriage in such manner as to prevent the possibility of this standard becoming electrically charged from any defect in the electrical conductors contained within it.

Trolley standards.

80. An emergency cut-off switch shall be provided and fixed so as to be conveniently reached by the driver in case of any failure of action of the controller switch.

Emergency switch.

81. Sufficient guards shall be erected and maintained at all places where telegraph lines cross above the electric conductors of the tramways.

Guards.

82. The undertakers shall give immediate notice to the nearest police-station and also to the Local Government of the occurrence of any accident by explosion or fire, or of any other accident causing or likely to cause loss of life or personal injury in connection with the electric working of the tramways.

Accident to be reported.

PREVENTION OF INJURY TO TELEGRAPH LINES.

83. The undertakers shall construct their electric supply-lines and other works of all descriptions, and shall work their undertaking in all respects with due regard to the telegraph line established by, or license from, the Governor-General in Council, and to the currents in such telegraph lines, and shall use every reasonable means in the construction of their electric supply-lines and other works of all descriptions, and in the working of their undertaking to prevent

Undertaking to be worked with due regard to telegraph line.

injurious affection, whether by induction, or otherwise, to such telegraph lines or the currents therein.

(2) Where any question arises as to whether the undertakers have constructed their electric supply-lines or other works, or worked their undertaking in contravention of this rule, it shall be determined by the Local Government, and the undertakers shall be bound to make any alterations in, or additions to, their system which may be directed by the Local Government.

Undertakers to be liable for injury to telegraph lines.

84. If any telegraph line referred to in rule 83 is injuriously affected by the construction by the undertakers of their electric supply-lines and works or by the working of the undertaking by the undertakers, the undertakers shall pay the expense of all such alterations in such telegraph lines as may be necessary to remedy such injurious affection.

Explanation.—A telegraph line shall be deemed to be injuriously affected by an act or work, if telegraph communication by means of such line is, whether through induction or otherwise, in any manner affected by such act or work or by any use made of such work.

Notice to telegraph authority in certain cases and compliance with telegraph requirements.

85. Before any electric supply-line is laid down or any act or work in connection therewith is done within 10 yards of any part of a telegraph line (other than repairs or the laying of lines crossing such telegraph line at right angles at the point of shortest distance and so continuing for a distance of six feet on each side of such point), the undertakers shall, not more than 28 nor less than 14 days before commencing the work, give notice in writing to the telegraph authority, specifying the course of the line and the nature of the work, including the gauge of any wire, and the undertakers shall conform with such reasonable requirements (either general or special) as may from time to time be made by the telegraph authority for the purpose of preventing any telegraph line from being injuriously affected by the said act or work.

Settlement of differences between telegraph authority and undertakers.

86. Where any difference arises between the telegraph authority and the undertakers with respect to any requirements of the telegraph authority, it shall be referred to the Local Government for decision, and the orders of the Local Government thereon shall be final.

Exemption in case of emergency.

87. Nothing in the four last foregoing rules shall apply to any case in which the undertakers can show that the immediate doing of the act or execution of the work was required to avoid an accident, or otherwise was a work of emergency, and that they forthwith served on the officer in charge of the Central Government Telegraph Office at the town or station where the act or work was done a notice in writing of the execution thereof, stating the reason for doing or executing the the same without previous notice.

APPENDIX II.

REPORT OF THE JOINT SELECT COMMITTEE ON ELECTRIC POWERS (PROTECTIVE CLAUSES).

The Joint Select Committee—appointed to join with a Committee of the House of Lords to consider and report whether the grant of Statutory powers to use Electricity ought to be qualified by any prohibition or restriction as to Earth Return Circuits, or by any provisions as to Leakage, Induction, or similar matters, and if so, in what cases and under what conditions—framed the following CLAUSE, to be inserted in all Bills and Provisional orders which authorise any Company, Corporation or Person, collectively referred to as "the Undertakers," to use larger Electric Currents *for other than Electric Lighting purposes.*

1. The Undertakers shall, in the use of electric power under the provisions of this Act (Order), employ either insulated returns or uninsulated metallic returns of low resistance. (This clause not to apply in the case of railways, tramways, or tramroads in which the motive power is entirely self-contained).

2. The Undertakers shall take all reasonable precautions in constructing, placing, and maintaining their electric lines and circuits, and other works of all descriptions, and also in working their undertaking so as not injuriously to affect, by fusion or electrolytic action, any gas or water pipes, or other metallic pipes, structures, or substances.

3. The exercise of the powers by this Act (Order) conferred with respect to the use of electric power, shall be subject to the regulations set forth in the Schedule to this Act (Order), and to any regulations which may be added thereto or substituted therefor, respectively, by any order which the Board of Trade may, and which they are hereby empowered to make from time to time, as or when they may think fit, for regulating the employment of insulated returns or of uninsulated metallic returns of low resistance, for preventing fusion or injurious electrolytic action of or on gas or water pipes, or other metallic pipes, structures, or substances, and for minimising as far as is reasonably practicable, injurious interference with the electric wires, lines, and apparatus of other parties and the currents therein, whether such lines do or do not use the earth as a return.

4. The Undertakers using electric power contrary to the provisions of this Act (Order) or to any of the regulations set forth in the Schedule to this Act (Order) or to any regulation added thereto or substituted therefor by any order made by the Board of Trade under the authority of this Act (Order) shall, for every such offence, be subject to a penalty not exceeding ten pounds, and also in the case of a continuing offence to a further penalty not exceeding five pounds for every day during which such offence continues after conviction thereof: Provided always, that, whether any such penalty has been recovered

or not, the Board of Trade, in case in their opinion the Undertakers in the use of electric power under the authority of this Act (Order) have made default in complying with the provisions of this Act (Order) or with any of the regulations set forth in the Schedule to this Act (Order) or with any regulation which may have been added thereto or substituted therefor as aforesaid may by order direct the Undertakers to cease to use electric power, and thereupon the Undertakers shall cease to use electric power, and shall not again use the same unless with the authority of the Board of Trade, and in every such case the Board of Trade shall make a special report to Parliament notifying the making of such order.

5. The Undertakers shall take all reasonable and proper precautions in constructing, placing, and maintaining their electric lines, circuits, and other works of any description and in using their electric lines, circuits and other works so as not injuriously to interfere with the working of any wire, line, or apparatus, from time to time used for the purpose of transmitting electric power, or of telegraphic, telephonic, or electric signalling communication, or the currents in such wire, line, or apparatus. Provided always that the undertakers shall be deemed to take all such reasonable and proper precautions as aforesaid, if and so long as they adopt and employ, at the option of the undertakers, either such insulated returns or such uninsulated metallic returns of low resistance, and such other means of preventing injurious interference with the electric wires, lines, and apparatus of other parties, and the currents therein, as the Board of Trade shall direct, and in giving such directions the Board shall have regard to the expense involved, and to the effect thereof upon the commercial prospects of the undertaking. Provided also that at the expiration of ( ) years from the passing of this Act (Order) nothing in this sub-section shall operate to give any right of action in respect of, or to protect any electric wires, lines, or apparatus, or the currents therein, unless in the construction, erection, maintaining and working of such wires, lines, and apparatus, all reasonable and proper precautions, including the use of an insulated return, have been taken to prevent injurious interference therewith, and with the currents therein, by or from other electric currents. If any difference arises between the undertakers and any other party with respect to anything in this sub-section contained, such difference shall, unless the parties otherwise agree, be determined by the Board of Trade, or at the option of the Board by an arbitrator to be appointed by the Board and the costs of such determination shall be in the discretion of the Board, or of the arbitrator, as the case may be.

(6) Nothing in this section shall apply to the use of any electric line, circuit, or work of any company, corporation, or person authorised by Act of Parliament, or Provisional Order confirmed by Parliament, to supply energy for electric lighting purposes, so far as such use is limited to such purposes.

The Committee also agreed upon the following Resolutions in the nature of recommendations, viz:—

(1) The Committee having regard to the evidence before them, are of opinion that it is not in the present state of electrical science to the interest of the public to insist upon electrical tramways using an insulated return conductor, and that such insistance would retard the development of electric traction.

(2) The chief objections which have been urged before the Committee to an uninsulated return conductor are, first, the interference by leakage and induction with telephones; secondly, the interference by leakage and induction with railway signals; thirdly, the damage to systems of gas and water-pipes by the action of leakage currents.

(3) They are of opinion that the best known means of overcoming the first of these disturbances, is by providing an insulated return conductor for the telephones, and they have the less hesitation in recommending this course, as the evidence shows that telephone construction is already tending in this direction, and that better results are secured to the public by the use of a twisted metallic circuit insulated entirely from the earth.

(4) The second objection deserves serious consideration on account of the danger to the public, but the Committee are of opinion that the disturbance may be remedied at comparatively small expense by the adoption of an insulated metallic return by the Railway Companies.

(5) They consider that, although Electric Tramway and Electric Railway Companies should be allowed to use the wheels of carriages and the rails to complete the electric circuit, the currents should be produced and used in such a manner as to mitigate, as far as is practicable, any injurious effect to telephonic communication.

(6) The Committee are of opinion that it is desirable in every way to facilitate the use of complete insulated metallic circuits for telephones, and for this end they recommend that statutory powers be granted enabling telephone undertakers to lay their wires underground.

(7) The danger from fusion or electrolytic action appears to the Committee to have arisen from a faulty system of constructing electric tramways, and they are of opinion that it can be reduced by improved methods of construction so as to be practically negligible.

(8) The Committee, therefore, recommend that the Board of Trade shall, in virtue of the powers to be conferred upon them by each Act or order, make regulations to secure the best system of working electric tramways and railways, having regard to the expense involved by the carrying out of such regulations, and to the effect thereof upon the commercial prospects of the undertaking. The regulations to provide *inter alia*—

(*a*) That a return conductor, if in contact with the ground, shall be of such section and resistance as to have no difference of potential sufficient to set up injurious leakage currents in the earth.

(*b*) That, both with regard to the structure of the line, and to the method of generation and use of the electrical current,

everything shall be maintained up to the standard required by the Board of Trade; but, if the regulations are altered after the use of electric power on the line has been sanctioned, the undertakers shall not be required to alter the structure, or method of working of the line to conform to the more recent regulations, except for the public safety or unless it shall be proved to the satisfaction of the Board of Trade that any system of metallic pipes or structures is being substantially injured by the action of electricity escaping from the conductors, or for purposes other than public safety or injury to pipes or structures which the Board may think right, provided that the alterations do not in such last case cause substantial additional expenditure.

(c) That all such electrical tests shall be applied to the line by the undertakers as the Board of Trade may think necessary, and that a record of these tests shall be kept for the information of the Board of Trade

(d) That the Board of Trade shall have all reasonable facilities for making any tests they may think necessary, in addition to those recorded by the undertakers to enable them to insure the maintenance of satisfactory conditions.

(9) That the Committee regards with apprehension a large extension of the system of overhead wires in crowded centres

(10) It appears to the Committee to be just that undertakers proposing to use large currents should be required to give ample notice to those using small currents to enable them to protect themselves by insulation, and that with this view, and in reference to the clause agreed upon, a period of two years may fairly be allowed to Telephone and Telegraph Companies from the date of the passing of any Act (Order).

APPENDIX III.

REPORT OF THE COMMITTEE APPOINTED TO FURTHER CONSIDER THE BEST AND MOST UP-TO-DATE METHOD OF GUARDING TELEGRAPH WIRES FROM OVERHEAD ELECTRIC TRAMWAY WIRES.

THE Committee consider that Rule 81 of the Government of India may with advantage be amplified, as regards the Calcutta Tramways, by the following clause and accompanying explanatory memorandum:—

Clause.

[NOTE.—The expression "telegraph wire" includes all telegraph and telephone wires.]

"Efficient guards shall be erected and maintained at all places where telegraph lines unprotected with a permanent insulating covering cross above, or are liable to fall upon, or to be blown on to, the electric conductors of the tramways.

Provided that where the undertakers, have lines erected and other wires are made to cross them after erection, the guards should be paid for by the person whose wires are erected last

Where any difference or dispute arises between the owner of the telegraph line and the undertakers or their agents, the matter shall be determined by the Local Government in accordance with section 24 (5) of the Calcutta Electric Lighting Act (Bengal Act IX of 1895)"

The proviso, it will be noticed, is the third recommendation contained in the report of the Committee on the question of guarding aerial lines, dated 3rd May 1901.

As a guide to the best and most efficient way in which the guarding may be done, the Committee have adopted the following explanatory memorandum, based chiefly on a similar document framed by the Board of Trade in 1902:—

EXPLANATORY MEMORANDUM.

1. (1) Each guard wire must consist of a strand or wire of not less weight or conductivity than a No. 8 galvanised iron wire.

(2) Each guard wire must be efficiently connected to the rails at one point at least, and at intervals of not more than three spans.

(3) The resistance from the guard wire to the rail must be such that a short circuit between the trolley wire and guard wire will open the fuse or circuit-breaker protecting the section of trolley wire affected, and the gauge of the guard wire must be such that it will carry, without fusing, a current 50 per cent. greater than that required to effect this.

(4) The earth connection should be made by connecting the support to the rails by means of a copper bond. When first erected the efficiency of the foregoing arrangement shall be tested, and periodical tests shall be subsequently made to prove that the efficiency is maintained. The results of all such tests shall be submitted for approval to an officer appointed by Government in that behalf.

(5) The supports for the guard wires should be rigid, and of sufficient strength for their purpose, and at each support each guard wire must be securely bound in or terminated.

(6) The rise of the trolley boom shall be so limited that if the trolley leaves the wire, it will not foul any telegraph line.

2. Ordinary Guarding Arrangements.

Telegraph lines crossing trolley wires.

(1) Where there is only one trolley wire, two guard wires should be erected (Fig. 1).

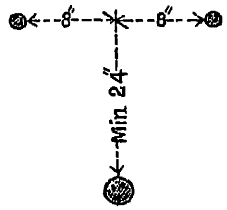


Fig. 1

(2) Where there are two trolley wires not more than 15 inches apart, two guard wires should be erected (Fig. 2).

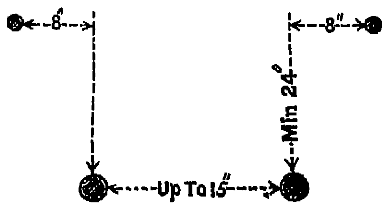


Fig. 2.

(3) Where there are two trolley wires and the distance between them exceeds 15 inches, but does not exceed 48 inches, three guard wires should be erected (Fig. 3).

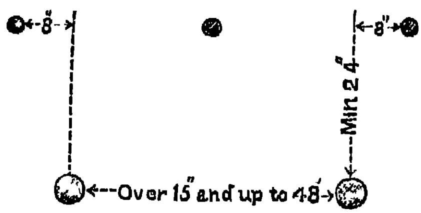


Fig. 3.

(4) Where the distance between the two trolley wires exceed 48 inches, each trolley wire should be separately guarded (Fig. 4).

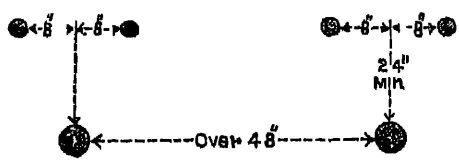


Fig. 4.

3. Ordinary Guarding Arrangements.

Telegraph lines paralled to trolley lines.

(1) Where the horizontal distance between a telegraph wire and a trolley wire is 20 feet or less the same guarding arrangements shall be made on the side towards the telegraph line as are described in clause 2 of this memorandum, but if rendered necessary by the conditions, the guard wire may be placed at a greater distance than 8 inches horizontally from the trolley wire. The height of such guard wires shall in no case exceed 30 inches above the trolley wire.

(2) When the telegraph wires are of such a height relatively to the trolley wires as to make it possible for a broken wire to fall on an arm, stay or span wire, and to slide down into proximity to a power wire, guard hooks should be fitted, which, in the case of span wires, should be triple in view of the twisting of the span wire.

4. Special Guarding Arrangements.

In exceptional cases, such as in exposed positions or for unusually heavy telegraph lines, special precautions should be taken. The following are a few examples:—

(1) At junctions or curves, where parallel guard wiring would be complicated, two guard wires may be so erected that a falling wire must fall on them before it can fall on the trolley wire.

(2) In case of specially heavy telegraph lines (*i.e.*, lines carrying more than 24 wires) the guard wires should, in the absence of an agreement to the contrary, be of the cradle or hammock type suspended beneath the telegraph lines from special posts.

(3) In other cases, subject to mutual agreement between the parties, the owners of the crossing wires should substitute cables, either aërial or underground according to circumstances.

(4) It is desirable, where possible, to divert telegraph lines from above trolley junctions and trolley wire crossings, and undertakers should endeavour to make arrangements to that effect with the owners of telegraph wires.

APPENDIX IV.

POST OFFICE TELEGRAPHS (GREAT BRITAIN)

RULES FOR GUARDING AËRIAL LINES.

April 1899.

MEMORANDUM for the information of Owners of Power Circuits as to precautions to be taken to protect telegraph wires, the property of the Postmaster-General, from Overhead Electric Light, Tramway, or to other power carrying wires, called herein "Power Circuits."

Compliance with the following regulations is required by the Postmaster-General under the section of the Act or order which authorises the undertaking in which provision is made for the protection of the Postmaster-General, but this requirement shall not be deemed to be the only requirement which may be made by the Postmaster-General under the said provision, and shall not prejudice any other reasonable requirement made by him under such provision.

A. Guard wires:—

In all cases in which a telegraph wire is crossed by a Power Circuit or where they are so placed relatively to one another that they are liable to come into contact, guard wires must be so erected as to prevent the possibility of such an occurrence.

(*a*) In cases in which the Power Circuit is below a telegraph wire, the following regulations shall be observed:—

1. A sufficient number of guard wires shall be erected over the Power Circuit to prevent a broken telegraph wire from touching the latter.

2. Where the Power Circuit consists of a single wire, or of two wires close to either, two guard wires shall be used. These shall overlap the Power Circuit eight inches on each side so that the broken end of a telegraph wire falling across them shall hang clear of the Power Circuit. In no case will the use of a single guard wire be permitted.

3. Where the wires of the Power Circuit are so far apart that two guard wires will not afford sufficient protection, then the guard wires shall be increased in number to a suitable extent, or an efficient method of lacing across with No. 12 S.W.G. wire for a distance of three feet on each side of the crossing may be adopted.

4. Where a telegraph wire runs parallel to a Power Circuit, and occupies a position vertically above it, guard wires shall be fixed overlapping the Power Circuit as in the case of crossings, but in all such cases the guard wires shall be laced across with No. 12 S.W.G. wire at intervals or not more than 18 inches for such a length as may be necessary to afford protection.

5. The size of the guard wires shall be not less than No. 8 S.W.G. or its equivalent, and these wires shall be erected as to have a factor of safety of at least three at winter temperature.

6. The guard wires shall be terminated at every support on a suitable appliance for the safe attachment of the wire so as to utilize its full strength.

7. The guard wires shall be fixed preferably on independent arms, but in all cases they shall be supported in a sufficiently rigid manner to hold up the weight of the telegraph wires should they fall across them.

8. The guard wires shall be not less than one foot six inches or more than three feet above the Power Circuit.

9. The guard wires shall be well earthed at every support

(*b*) Where the Power Circuit is above the telegraph wires, the same principle shall be followed in designing the mode of protection.

10. The overlap of eight inches referred to in paragraph 2 will in this case refer to the Department's wires.

11. In this case the guard wires may be fixed on the Department's poles where such a course is obviously advantageous. Inasmuch, however, as Departmental officials only can be authorised to deal with the Department's lines, it is essential that when guard wires are so placed their installation and maintenance be undertaken and the whole of the materials be provided by the Department.

B. Fuses:—

12 In all cases the telegraph wires shall be fitted with fuses at suitable points on both sides of the Power Circuit.

13. Where crossings are numerous in a locality, the whole of them may be protected by providing two sets of fuses, one at each of the extremities of the area covered by the Power Circuits.

(Paragraphs 14 and 15 concern Departmental Officers only.)

D. Cost:—

16. The whole cost of protecting the Department's circuits shall be borne by the body owning the Power Circuit.

APPENDIX V.

ELECTRICAL ACCIDENTS.

DURING a recent storm several horses received shocks by coming into contact with fallen wires, and the *Englishman* suggested that the public should be instructed as to how to proceed in such circumstances. With this end in view I append the following note on the treatment of the injured (Paris) and also the "Instructions to the police" issued at Cape Town by Mr. A. P. Trotter, then Government Electrical Engineer, and now Electrical Adviser to the Board of Trade. I have only made such alterations as are necessary in view of the change of locality.

ELECTIC SHOCKS.

THE TREATMENT OF VICTIMS.

I. Whenever a person is injured by the falling down of, or from contact with, an electric wire, those present must not, under any circumstances, touch the electric wire with their hands.

II. It is important to release the victim from the wire as soon as possible, and a piece of dry wood (broomstick for example) will serve the purpose. This should be done with the greatest precaution. With the same piece of wood, the wire can then be pushed aside, if it obstructs the way.

III. The central power-house, through the nearest police or telephone station, should then be notified to stop the current, and the nearest physician called, who will treat the patient similarly to a drowned person.

The following recommendations should be given publicity where the accidental falling of an electric wire can cause injury. Although the instructions are given that the physician should be called, the bystanders should not wait before giving assistance to the stunned patient. It is therefore, wise to publish the methods for aiding such cases as recommended by the Conseil D'Hygiene et de Salubrité du Department de la Seine. The patient is removed from the place of accident, the neck and chest freed, and resuscitation is then attempted by any of the following methods:—

(*a*) Rythmical traction of the tongue.
(*b*) Artificial respiration.

It is best, if possible, to combine two methods.

(*a*) Rythmical traction of the tongue.—The manipulation should be commenced as soon as possible.

(1) The patient is placed on the back: the head slightly turned to one side.

(2) The jaws are opened; separating them by force if necessary.

(3) The tongue is seized between the thumb and index finger with a handkerchief or cloth.

(4) The tongue is forcibly drawn out of the mouth repeating twenty times a minute. Do not be afraid to draw it out too strongly: it is necessary that at each traction the jaws be opened wide and that the tongue protrudes entirely beyond the mouth.

(5) These movements of the traction of the tongue should be continued with persistence for at least one hour.

N. B.—If the operator becomes confused by the number of tractions, he can regulate the number by his own respiration and perform traction on the tongue of the patient with each respiration of his own.

The appearance of hiccough or vomiting is a favourable sign; when it occurs it is necessary to continue the tractions on for a long time.

(6) Artificial respiration.—The patient is placed on his back, the shoulders slightly elevated, the mouth opened and the tongue well drawn out. The following methods are used:

(1) The arm of the patient is grasped at the elbows and brought firmly against the side of the thorax. Then the elbows are moved upwards above the head, describing the arc of a circle, and lastly bringing them back to their first position and press firmly against the side of the thorax. Repeat these movements about twenty times a minute and continue until respiration is re-established.

(2) Place the hands flat upon the inferior and lateral parts of the thorax, using vigorous pressure and letting go immediately after the pressure. Repeat these movements about twenty times per minute: continuing same until normal respiration supervenes.

INSTRUCTIONS TO POLICE IN CASE OF ACCIDENTS.

If a wire falls in a street in which the electric tramway runs, and the end hangs loose, or lies on the ground, the best thing to do is to *leave it alone* until one of the Tramway Company's staff comes. In such a case the best thing that a constable can do is to prevent anybody from touching the wire.

If a wire as it lies on the street is an obstruction to the traffic, it may be pulled on one side, by means of a stick (a walking stick with a hooked handle would do well) or it may be moved by using rubber gloves. It would be better to allow the traffic to be impeded than that the constable should leave the wire in order to get the gloves from the nearest station.

The thick wires which run above the middle of the street are called the trolley wires. They convey the current to the cars. Smaller wires called span wires, are stretched across the streets to support the trolley wire. Other small wires are erected in some streets for the purpose of preventing telephone wires from falling on the trolley wires. If a telephone wire falls and is kept by the guard wires from touching the trolley wires, or if it touches a span wire, and does not touch the trolley wire, no shock can be given by it. If the loose end is an obstruction to traffic, and if it can be drawn away and tied up without any risk of touching the trolley wire while doing so, this may be done. Rubber gloves should be used. If there is any risk of touching the trolley wire with the wire which is to be handled, it is better to *leave it alone* and to see that nobody else touches it until a tramway man comes.

If a wire falls across a trolley wire, or the trolley wire itself touches the tramway rails, there will be a violent flash. When this flash occurs, an automatic switch at the Tramway Works will be opened, and the electric supply will be cut off on the section on which the accident has happened The trolley wire is divided into sections of half a mile in length. As long as the switch is open, no tramcar can run on that section, and the wires are harmless. As soon as the attendant at the works sees the automatic switch fall open, he will try to close it, in case the cause has been a momentary one. If, however, the wire still lies touching the rails, he will be unable to keep the switch closed. The same thing may happen if a wire falling on the trolley wire touches a tramway pole, electric lighting pole, telegraph pole or other metal work connected with the ground; but this is not certain.

It is very undesirable to make a connection between a wire and the tramway rails or any other metal work intentionally; because the flash which will occur will be so brilliant that it will unnecessarily alarm the bystanders, and may so dazzle the constable who causes it to touch, that he may be unable to see anything for a minute or so.

It is a good thing to keep the wire on the rail if it touches it all. It may be held there with a stick, but it is advisable not to hold it there by standing on it, since if the rail is dirty a slight shock, but enough to cause the person standing to fall, might result.

If the end of a wire hangs loose in the street, and is an obstruction to traffic, a rope or piece of strong string may be put round it with a "half hitch," without touching the wire with the hands, and it may then be drawn on one side. Great care must be taken in doing so that it touches no other wire, pole or metal work.

The electric pressure (500 to 550 volts) used by the tramway is not sufficient to give a fatal shock to a human being. It is sufficient to produce serious burns. The pressure used for electric lighting in Calcutta is 220 volts between any wire and the earth. The highest pressure between any wires accessible to the public is 440 volts; 220 volts would probably kill a horse.

If a wire falls on a person and winds round him, or becomes entangled in the clothing, the wire should be pulled away with a stick, or by wrapping the hand in a dry coat, or by means of rubber gloves, taking special care that the wire does not touch the skin either of the victim or of the rescuer.

A severe electric shock may produce sudden stoppage of the respiratory and heart muscles. If the stoppage of the heart's action is complete, it is doubtful if anything can be done.* But in some cases the stoppage is not complete, and animation is only suspended. The condition is similar to that of apparent death by drowning, and the well-known method of producing artificial respiration should be resorted to without delay.

* A case was recently reported in England, where standing the apparently lifeless man on his head and thumping his chest eventually started the heart's action again.

J. W. M.

Summary.

If a wire falls harmlessly, leave it alone, and prevent any one from touching it.

Only the trolley wire, or wire touching it, does mischief.

The electric current is, as it were, always trying to pass from the trolley wire direct to the tramway rails, or through the earth to the rails.

A shock can only be felt when the body forms part of a path by which the current can pass from the trolley wire to the rails.

The electric current cannot pass through *dry* wood, cloth or rope.

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